

solutions for all

Agricultural Sciences

W Burger

Z Rose

Learner's
Book



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Solutions for all Agricultural Sciences

Grade 11

Learner's Book

W Burger

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Topic 1

Basic Agricultural Chemistry

What will you learn about in this topic?

- Basic chemistry terminology important in Agriculture: matter, atoms, molecules, ions, valency, isotopes, elements, compounds and mixtures
- The use and interpretation of the periodic table of elements
- Chemical bonding
- Organic and inorganic substance formations and their molecular structures
- Alkanes and alcohols
- Fatty acids
- Lipids
- Proteins
- Carbohydrates.



Let's talk about this topic

The expanding developments in the fields of animal and plant nutrition have resulted from the application of knowledge and techniques from many different sciences. The physiologist and the biochemist have worked together to study the nutrient needs of living organisms. Thanks to the efforts of the organic chemist, different sources of nutrients have become available to the livestock farmer and to the crop farmer.

Agricultural science is the science of chemical compositions and changes involved in the production, protection and use of crops and livestock.

Every scientific discipline that contributes to agricultural progress depends in some way on chemistry. Agricultural chemistry is not a distinct discipline, but a common thread that ties together genetics, physiology, microbiology, entomology and many other sciences that have an effect on agriculture.



Unit 1: Introduction to basic chemistry

What will you learn about in this unit?

- Basic chemistry terminology important in Agriculture: matter, atoms, molecules, ions, valency, isotopes, elements, compounds and mixtures
- The general structure of an atom
- The main types of particles of an atom and their respective charges
- The differences between elements, compounds and mixtures (with relevant examples)
- The basic interpretation of the periodic table of elements
- The arrangement of electrons around the nucleus and valency
- The relation between atomic numbers and number of particles in the nucleus
- The formation of ions
- Using the Lewis structures to illustrate the electron structure of an atom
- The differences between acids and bases.

Let's talk about this unit

Chemistry sometimes creates a feeling of fear among learners because this field of study seems to be difficult. However, if you understand the basic concepts, it is a very interesting subject.

What do I know already?



You have already been introduced to some of the elements in the periodic table. You have learnt about calcium, phosphorus, magnesium and iodine. You discovered that these four elements together are an important part of a healthy diet.

Check myself

- Are children who grow up in South Africa likely to develop rickets? Explain your answer.

Word bank

A B C

Atom: Pure substance consisting of one type of atom

Compound: Pure substance consisting of two or more different atoms

Element symbol: An abbreviation of an element's name found on the periodic table

Element: A substance composed of atoms having an identical number of protons in each nucleus. Elements cannot be reduced to simpler substances by normal chemical means

Heterogeneous mixture: A mixture with a non-uniform composition

Homogeneous mixture: A mixture with a uniform composition

Isotope: One or two or more atoms having the same atomic number but different mass numbers

Matter: Any substance which has mass and occupies space

Mixture: Two or more different substances not chemically combined

Molecule: The smallest particle of a substance that retains the chemical and physical properties of the substance and is composed of two or more atoms

Periodic table: A tabular arrangement of the elements according to their atomic numbers so that elements with similar properties are in the same column.

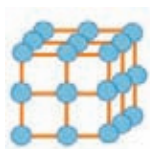
What I still need to know



Important terminology

Let's explore some important terminology that we will be dealing with in Agricultural chemistry.

Matter



Solid



Liquid



Gas

Figure 1.1: Three states of matter

Matter consists of extremely small particles called molecules. These molecules are continuously in motion (they possess kinetic energy), but they are also attracted to one another by a force known as cohesion.

Matter can exist in three forms called states of matter, as shown in Figure 1.1, and described below.

- A **gas** (vapour) has no fixed volume or shape, and so it conforms to the volume and shape of its container. A gas can be compressed to occupy a smaller volume, or it can expand to occupy a larger one. The particles in a gas state of matter have very high kinetic energy and will move about very rapidly. They collide against one another so strongly that they move quite far apart and as a result the cohesive forces between them are extremely weak.
- A **liquid** has a distinct volume independent of its container, but has no specific shape. It assumes the shape of the portion of the container that it occupies. The particles in a liquid state of matter have greater kinetic energy, they vibrate in a less restricted area, are not held to one another quite so strongly and can move about, although they are still attracted to one another quite strongly.
- A **solid** has both a definite shape and a definite volume, in other words it is rigid. Neither liquids nor solids can be compressed very much. The particles in a solid state of matter do not have much energy, they can only vibrate around a restricted area and the forces of cohesion between the molecules are very strong.

Elements

An element is a material which cannot be broken down or changed into another substance using a chemical reaction. Therefore, we can think of elements as the basic chemical building blocks of matter. There are 117 known elements.

The most abundant element in the universe is hydrogen, which makes up about 75% of all matter. Helium makes up most of the remaining 25%. Oxygen is the third most abundant element. All of the other elements are relatively rare.

Atom

Atoms are very small and cannot be seen with the naked eye. One million atoms can fit across the width of a strand of hair. An atom is the defining structure of an element, which cannot be broken by any chemical means. A typical atom consists of a nucleus (made up of protons and neutrons) with electrons circling around this nucleus, as shown in Figure 1.2.

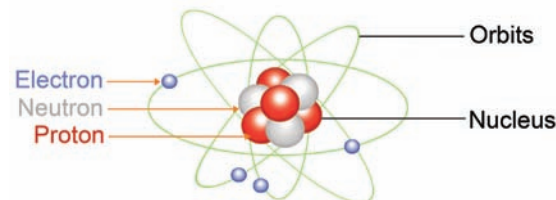


Figure 1.2: Structure of an atom

- **The proton:** A proton is a very small, positively charged particle found in the **nucleus** of all atoms. Its mass is approximately 1 u (or 1 atomic mass unit).
- **The neutron:** A neutron is a very small, uncharged (or neutral) particle found in the nucleus of all atoms, except the normal hydrogen atom. Its mass is also approximately 1 u.
- **The electron:** An electron is an extremely small particle which is negatively charged and is found in different energy levels outside or around the nucleus in an orbital. Its mass is negligible, about 1/2000 u.

In a neutral atom the number of protons equals the number of electrons (because their charges are equal but opposite), but the number of neutrons can vary.

Molecule

While an atom is the smallest particle into which an element can be broken down, a molecule is the smallest particle of a substance which can exist independently and still display the properties of that substance. Some elements (such as hydrogen) consist of molecules made up of two atoms (H_2), while others (such as helium) consist of molecules of single atoms (He). An atom of hydrogen is H, while a molecule of hydrogen is H_2 . An atom of helium is He and it is also a molecule of helium.

The differences between elements, compounds and mixtures

Everything in the universe is made up of matter. A substance is pure and is made of **either** elements or compounds, as described below:

- **Elements** are the simplest form of matter found on the periodic table, such as hydrogen, oxygen, chlorine, sodium and iron. Hydrogen gas (H_2) for example is an element because it contains only hydrogen atoms.
- **Compounds** occur when two or more atoms are chemically combined and can be represented with a formula, for example, water (H_2O). Sulphuric acid (H_2SO_4) is also a compound which consists of hydrogen atoms, sulphur atoms and oxygen atoms and each molecule of sulphuric acid consists of two H-atoms, one S-atom and four O-atoms bonded together.

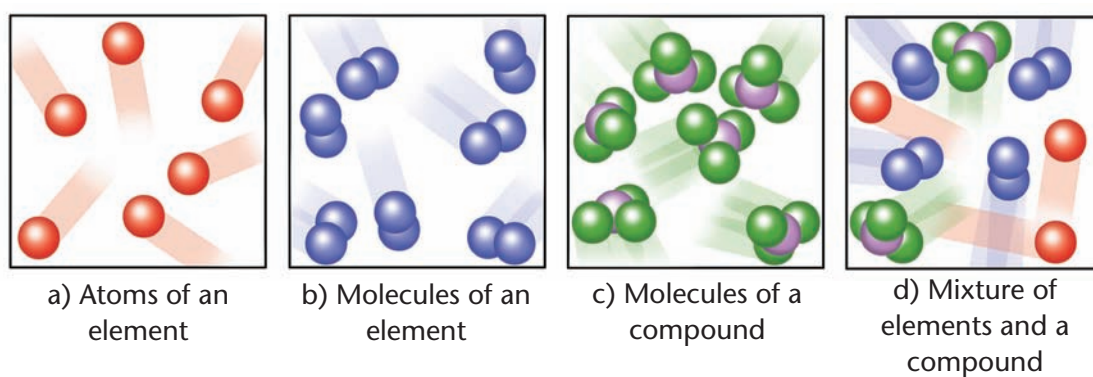
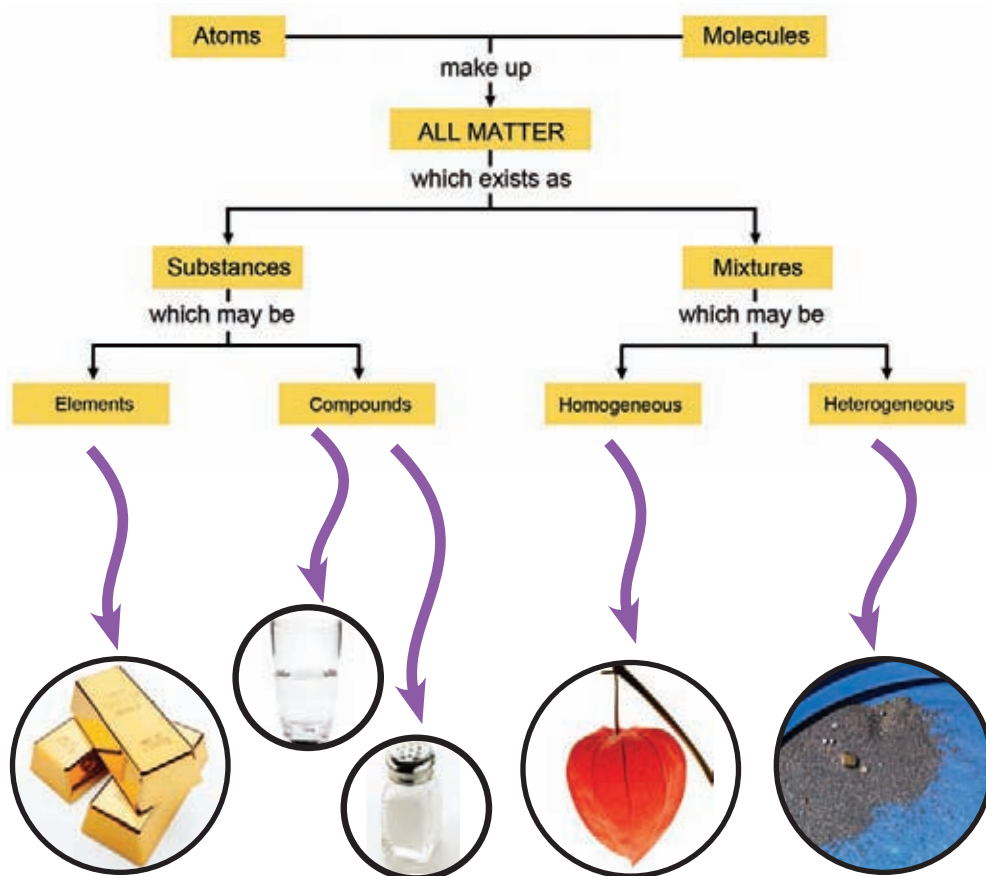


Figure 1.3: Illustrations of the atoms of an element, molecules of an element, molecules of a compound and a mixture

A **mixture** is when two or more substances are in the same place at the same time. Most common substances that we deal with every day are not pure substances but mixtures. Air is a mixture of gases, soil is a mixture of many substances, and so on. Mixtures can be heterogeneous or homogeneous, depending on how the solute is spread through the mixture:

- **Heterogeneous mixtures** are not mixed evenly and each sample can be different, such as air and soil samples, a mixture of sand and sugar, or a mixture of sand particles and clay particles.



- **Homogeneous mixtures** are the same throughout like creamy peanut butter, vanilla ice cream, pure air, sugar or sugar mixed with water – you cannot distinguish between the sugar and water particles which have formed a solution that exists in one phase (or state) of matter (in this case a liquid). A solution can be described as an intimate homogenous mixture of substances which are in the same phase.

The flowchart in Figure 1.4 shows the difference between elements, compounds and mixtures.

Figure 1.4: Flowchart showing the difference between elements, compounds and mixtures



Mixtures (and solutions) are different from compounds because the constituents of a mixture can be separated by simple physical means, such as filtration, diffusion and distillation, while the constituents of a compound cannot. The composition of a mixture (or a solution) can also be varied as you want, but the composition of a compound is fixed and invariable.

Examples

Salt water is a tricky one because we know we can write a formula for salt (NaCl) and water (H_2O), but it is a mixture, because when mixed in solution, these compounds do not combine.

When sugar is dissolved in water we call the water the solvent, sugar the solute and the mixture the solution. It is not always easy to distinguish between solute and solvent (except for solids in a liquid solution when the liquid is always the solvent). The general rule is to regard the constituent which is in the majority as the solvent.

The following table shows more examples of solutions (mixtures).

State of matter	Solute	Solvent	Example
Gas	Gas Liquid Solid	Gas Gas Gas	Air (oxygen dissolved in nitrogen) Water vapour in air Sulphur fumes in air
Liquid	Gas Liquid Solid	Liquid Liquid Liquid	Soda water (CO_2 in water) Oil in petrol Salt in water
Solid	Gas Liquid Solid	Solid Solid Solid	Ammonia absorbed in charcoal Mercury dissolving in gold Brass (mixture alloy of zinc and copper)

Periodic table of elements

There are more than a hundred elements known in nature. These elements are arranged in a table, called the periodic table (see Figure 1.5). Each square on the periodic table gives information about an element. On many printed periodic tables you can find an element's symbol, atomic number, and atomic weight. Elements are listed according to their atomic number, for example C is carbon with the atomic number of 6.

Periodic Table of the Elements

The periodic table is organized into groups (columns) and periods (rows). The groups are labeled 1A through 8A at the top, and the periods are labeled 1 through 7 on the left. The lanthanide and actinide series are shown below the main table, labeled 'Lanthanides' and 'Actinides' respectively. A legend at the bottom identifies the following categories: Alkali Metals (pink), Alkaline Earth (orange), Basic Metal (yellow), Halogen (green), Noble Gas (blue), Non Metal (light blue), Rare Earth (purple), Semi Metal (light green), and Transition Metal (grey).

Figure 1.5: Periodic table

For the study of Agricultural Sciences only the first twenty elements (according to atomic numbers) are important, i.e. periods 1, 2, 3 and the first two elements in period 4 (or the upper parts of sub-groups I to VII).

The diagram illustrates the periodic table's structure. The top part, labeled 'PERIODS', shows the horizontal arrangement of elements. The bottom part, labeled 'GROUPS', shows the vertical arrangement of elements. The elements are color-coded to represent different chemical families.

Figure 1.6: Periodic table groups and periods

The periodic table helps predict some properties of the elements as compared to each other. For example, atom size decreases as you move from left to right across the table and increases as you move down a column. Energy required to remove an electron from an atom increases as you move from left to right and decreases as you move down a column. The ability to form a chemical bond increases as you move from left to right and decreases as you move down a column.

The periodic table is a chart which organises the chemical elements. The elements are categorised according to the following characteristics:

- Atomic number – number of protons in the nucleus
- Atomic mass – sum of the number of protons plus neutrons in the nucleus
- Group – columns or multiple columns in the periodic table. Elements in a group share similar chemical and physical properties
- Period – rows from left to right in the period table. Elements in a period have the same number of energy shells.

Periodic table groups (columns of elements)

Elements within a group share several common properties. Groups are elements that have the same outer electron arrangement. The outer electrons are called valence electrons. Because they have the same number of valence electrons, elements in a



group share similar chemical properties. The Roman numerals listed above each group are the usual number of valence electrons. For example:

- **Group IA** is the **alkali metals** where the element has one electron in the orbital, for example sodium, potassium and rubidium. Alkali metals form salts and many other compounds. These elements are less dense than other metals, form ions with a +1 charge, and have the largest atom sizes of elements in their periods. The alkali metals are highly reactive and produce solutions that feel slippery and burn the skin (alkaline solutions).
- **Hydrogen** has a single positive charge like the alkali metals, but at room temperature it is a gas that does not act like a metal. Therefore, hydrogen is usually labelled as a non-metal.
- **Group IIA** is the **alkaline earth metals** where the element has two electrons in the orbital, for example calcium and magnesium. These metals form many compounds; they are reactive metals that produce alkaline solutions. They have ions with a +2 charge. Their atoms are smaller than those of the alkali metals.
- **Groups IB to VIIIB** are the **transition metals**, for example iron and gold. These elements are very hard, with high melting points and boiling points. The transition metals are good electrical conductors and are very malleable. They form positively charged ions. The transition metals include most of the elements, so they can be categorised into smaller groups:
 - **Metal triads** are metals with very similar properties, usually found together, for example iron triad consists of iron, cobalt and nickel
 - **Lanthanides** are the elements in the second last row of the periodic table with atomic numbers following lanthanum. Lanthanides are silvery metals that tarnish easily. They are relatively soft metals, with high melting and boiling points. The lanthanides react to form many different compounds. These elements are used in lamps, magnets, lasers, and to improve the properties of other metals
 - **Actinides** are in the row below the lanthanides, with atomic numbers that follow actinium. All of the actinides are radioactive, with positively charged ions. They are reactive metals that form compounds with most non-metals. The actinides are used in medicines and nuclear devices.
- **Group VIIA** is the **halogens** where the element has seven electrons in the orbital, e.g. chlorine, bromine and iodine. Halogens are amongst the most reactive of all elements and combine violently with alkali metals to form salts. We find these elements in bleaches, disinfectants, and salts. These non-metals form ions with a -1 charge. The physical properties of the halogens vary.
- **Group 0** is the **noble gases** (inert), for example helium (He) and neon (Ne), and are used to make lighted signs, refrigerants and lasers. The noble gases are the least reactive elements, because they have little tendency to gain or lose electrons.

Periodic table periods (rows of elements)

- The period number of an element signifies the highest unexcited energy level for an electron in that element. The number of elements in a period increases as you move down the periodic table, because there are more sublevels per level as the energy level of the atom increases. All of the elements in a period have the same number of atomic orbitals:
 - In period 1 (top row) every element has one orbital for its electrons

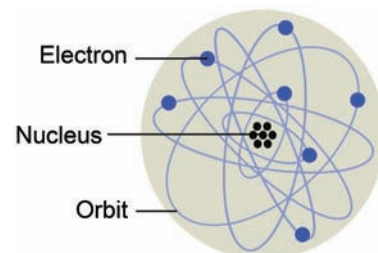


Figure 1.7: Atomic orbitals

- In period 2 (second row), all of the elements have two orbitals for their electrons
- And so it continues to period 7.

The arrangement of electrons around the nucleus and valence

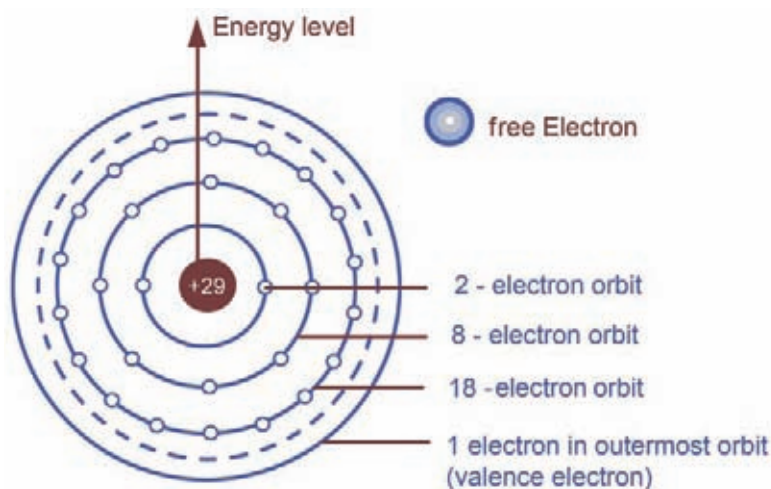


Figure 1.8: Electrons orbiting the copper nucleus

Electrons orbit the nucleus at certain distances from the nucleus. Each orbit corresponds to a certain energy level. The electrons in the outermost orbit are called **valence electrons**. They have higher energy and are less tightly bound to the atom than those closer to the nucleus.

The following (Figure 1.8) is an example of the copper (Cu) atom, showing the electrons orbiting the nucleus at various distances from the nucleus.

If a valence electron acquires a sufficient amount of energy, it can escape from the outer orbit. The escaped valence electron is

called a **free electron**. It can migrate easily from one atom to another.

When two atoms combine or bond with one another the bonding takes place between the outer electrons of each of the atoms; for this reason we call the outer electrons of an atom its bonding or **valence electrons**. This occurs because when two atoms are very close to one another it will be their outside electrons which affect one another. (The two nuclei are not directly involved, although they really control the bonding because they attract all the electrons.)

One atom reacts with another in order to fill its outer energy level with electrons because this is a more stable configuration.

The relation between atomic numbers and number of particles in the nucleus

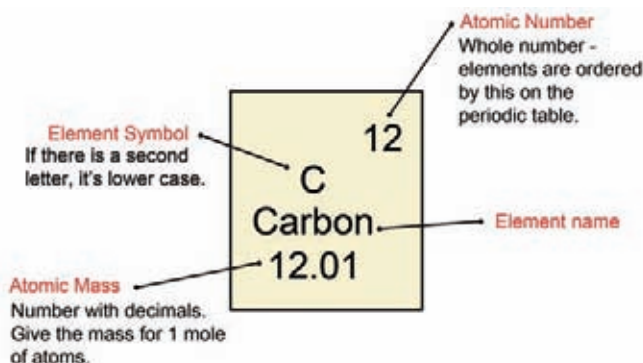


Figure 1.9: Atomic number of an element in the periodic table

The atomic number of an atom is probably the most important number in chemistry, because it determines the element of which the atom is a part. A certain atomic number is unique to a particular element and is shown in the periodic table, as illustrated in Figure 1.9.



Example

If an atom has atomic number 12, we know the following:

- it has 12 protons in each nucleus
- it belongs to element number 12, which is magnesium with symbol Mg
- it has 12 electrons in its energy levels outside the nucleus (because the atom is electrically neutral)
- it occupies a specific place in the periodic table (Group II, period 3) which gives it a particular set of properties.

The mass number of an atom is a number indicating how many particles (nucleons) there are in the nucleus of that atom, that is:

mass number = number of protons + number of neutrons,

or conversely: number of neutrons in a nucleus = mass number – atomic number.

Because atomic numbers and mass numbers are so important in chemistry, they were given special symbols and are indicated or written in a special way, for example: ${}_{92}^{238}\text{U}$

We can work out the following information from this:

- the symbol U: the element is uranium
- the number 92 (which is usually written on the left of the symbol – but always at the bottom) is the atomic number (Z), so there are 92 protons in the nucleus and therefore 92 electrons in the various energy levels
- the number 238 (which is always written at the top) is the mass number (A), so there are 238 nucleons (particles in the nucleus) and since 92 of these are protons, the rest must be neutrons – namely 146 ($238 - 92 = 146$).

We can see from Figure 1.10 that as the atomic mass of the elements increases, so their position on the periodic table changes.

As we move left to right (and top to bottom) on the periodic table, the number of protons, neutrons and electrons all increase. More subatomic particles lead to higher mass.

The formation of ions

An ion is formed when an atom or a group of atoms gains an electron to become negatively charged or loses an electron to become positively charged, as Figure 1.11 shows.

The formation of ions is the first step in the process of a chemical bonding, known as ionic bonding. During the formation of an ion (atom with a charge):

- a cation will form: positively charged ion resulting from the loss of electrons.
- an anion will form: negatively charged ion resulting from the gain of electrons.

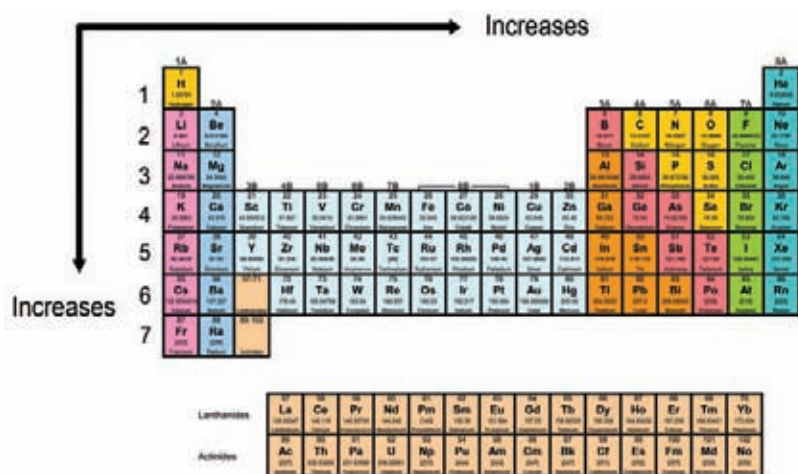


Figure 1.10: Atomic mass increase on the periodic table

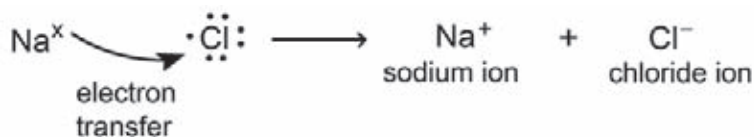


Figure 1.11: Ionic bonding between sodium and chlorine

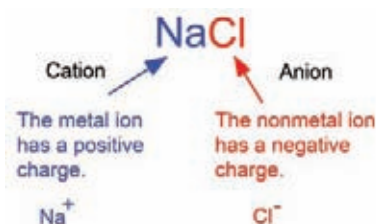


Figure 1.12: Ionic bonding between sodium and chlorine

From this example (Figure 1.12) we can see that:

- The sodium atom becomes a positive charged sodium ion because there are now 11 protons which are positive charged and only 10 electrons with a negative electrical charge – a majority of one positive charge.
- The chloride atom has one extra negative charged electron which results in a negative charged ion – 18 electrons versus 17 protons.
- The two ions – sodium and chloride are now attracted to one another to form the ionic compound, sodium chloride (with formula, NaCl). In this compound both ions have full outside energy levels which means that they are now stable – although they become (negative) charged.

This not only happens to single atoms, but to groups of atoms or molecules where an electron or a positive particle (a proton) may be attracted and change it to an ion, for example:

In some cases atoms will achieve full outer energy levels by the transfer of one or more electrons from the one atom to the other. This results in the atom which loses one (or more) electrons becoming a positive charged ion. The atom which gains one or more electrons becomes a negative ion.

ammonia molecule + proton $\rightarrow$ ammonium ion



It is important for us to look at the electron structure of atoms. To do this we make use of the **Lewis structure**.

H•	or	H ^x	Hydrogen (only one electron)
He:	or	He ^x	Helium (2 electrons)
•C•	or	^x C ^x	Carbon (6 electrons: 1 st level 4 in outside level)
•N•	or	^x N ^x	Nitrogen (7 electrons: 5 in outer level)
•O•	or	^x O ^x	Oxygen (8 electrons: 6 in outer level)
•Ne:	or	^x Ne ^x	Neon (10 electrons: 2 in 1 st level - full 8 in 2 nd level - full)
•Na	or	^x Na	Sodium (11 electrons: 2 in 1 st level - full 8 in 2 nd level - full 1 in outer level)
•P•	or	^x P ^x	Phosphorus (15 electrons: 2, 8, 5)
•S•	or	^x S ^x	Sulfur (16 electrons: 2, 8, 6)
•Cl•	or	^x Cl ^x	Chlorine (17 electrons: 2, 8, 7)
•K	or	^x K	Potassium (19 electrons: 2, 8, 8, 1)
•Ca•	or	^x Ca ^x	Calcium (20 electrons: 2, 8, 8, 2)

Figure 1.13: Lewis structure examples

Lewis structure

In the Lewis structure the outer or valence electrons of an atom are represented by dots or crosses to show how they interact to fill their outer energy levels. (Note that the full inner levels are not shown.)

Some Lewis structures of important elements are shown in Figure 1.13.

From the examples in Figure 1.13, we can see:

- The helium atom has a full outside energy level, that is, two electrons in the first level. Neon also has a full outer energy level with eight electrons in the second energy level. Since they both have full outer energy levels, they will not take part in chemical reactions and are chemically inactive. They are both members of a group of chemically inactive elements known as the noble gases.
- Hydrogen is unique among the elements because it reacts to fill an outer level with only two electrons in it, in other words it is short of one electron.
- Nitrogen and phosphorus both have five valence electrons in their outer levels (three short) and will react in a very similar manner.

- Oxygen and sulphur both have six valence electrons (two short) and their reaction will show similarities.

Using the Lewis structure in bond pairs

The outer or valence electrons of an atom are represented by dots or crosses to show how they interact to fill their outer energy levels. The full inner levels are not shown. Figure 1.14 shows some examples of Lewis structures for bond pairs.

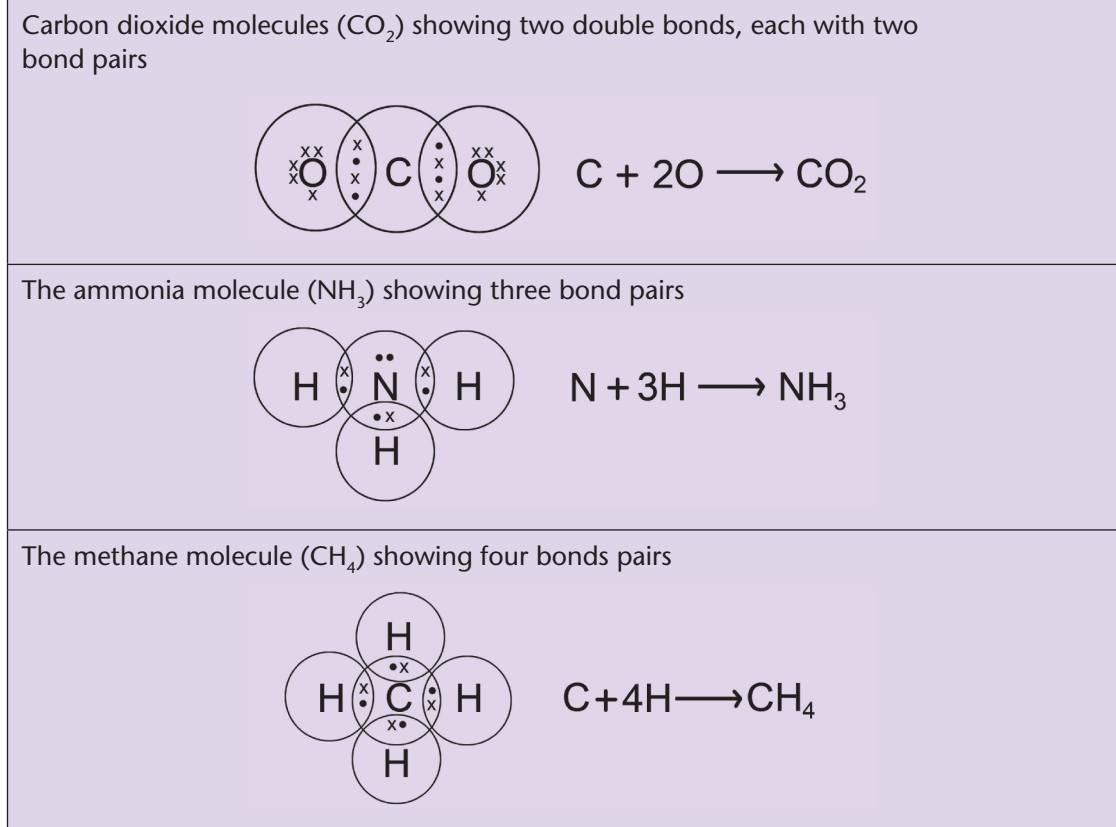


Figure 1.14: Lewis structure for bond pairs

Isotopes

Isotopes are atoms which have the same atomic number (so they are the same element), but have different mass numbers, because they have different numbers of neutrons in their nuclei. It is very important to remember that all the isotopes of an element are chemically identical (they have the same number of protons and therefore the same number of electrons), but they differ in mass (different number of neutrons). Because too few or too many neutrons can make a nucleus unstable, some isotopes of an element may be unstable, meaning that their nuclei may split or disintegrate, emit other particles and energy and change to other elements. This is the basis of the nuclear energy used in nuclear power stations and nuclear bombs.

In Figure 1.15 you can see the three isotopes of hydrogen.

${}^1_1\text{H}$	1 proton, 0 neutrons (1 electron) Name: 'normal hydrogen' or <i>protium</i> .
${}^2_1\text{H}$	1 proton, 1 neutron (1 electron) Name: <i>deuterium</i> ('deuter' = two - its mass no.)
${}^3_1\text{H}$	1 proton, 2 neutrons (1 electron) Name: <i>tritium</i> ('tri' = three - its mass no.)

Figure 1.15: Three isotopes of hydrogen

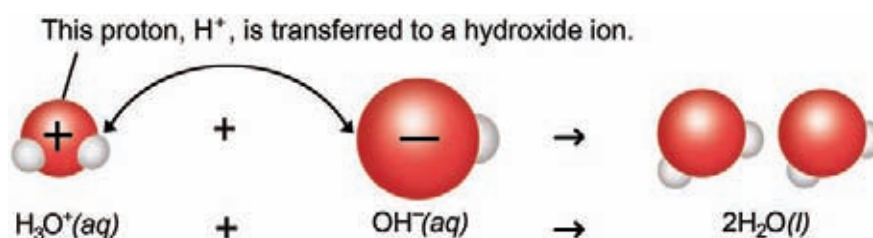


Figure 1.16: Transfer of the hydroxide ion

Acids and bases

An **acid** is a substance that donates an H^+ ion to another chemical species called a base.

A **base** is a substance that accepts (combines with) an H^+ ion.

Pure water is neutral. This means that pure water contains the same number of hydronium ions (H_3O^+) as hydroxide ions (OH^-).

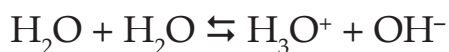


Figure 1.17: Pure water is neutral

When an **acid is added to water**, protons are transferred to the water molecules, and an excess of hydronium ions (H_3O^+) is formed. The acid will give up a proton and the water will accept a proton, as shown in Figure 1.18.

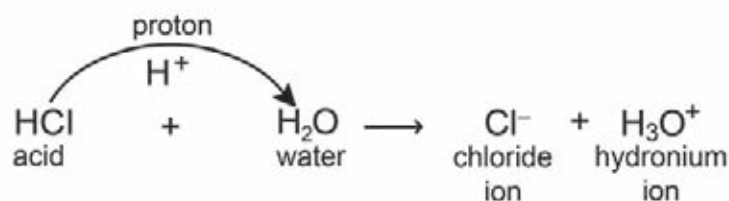


Figure 1.18: Adding acid to water



In this chemical reaction the acid molecules donate a proton (H^+) to the strongly polar water molecule to form a hydrated proton or the hydronium ion. This determines the acidity of the solution – the greater the concentration of H_3O^+ ions, the lower the pH.

In an **alkaline solution** protons are transferred from the water molecules to form an excess of hydroxide (OH^-) ions (or conversely a shortage of hydronium ions). The concentration of hydroxide (OH^-) ions determines the alkalinity of the solution – the greater the concentration of OH^- ions, the higher the pH.

When ammonia gas (NH_3) is dissolved in water, the water molecule will give up a proton (H^+) to form hydroxide ions (OH^-), as you can see in Figure 1.19. This is due to the strong attraction of the very polar molecules for the NH_3 molecules.

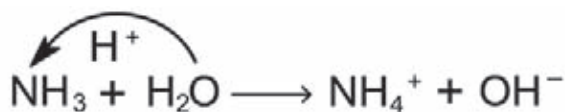


Figure 1.19: Dissolving ammonia gas in water

A base is therefore a substance which, when it is dissolved in water, will accept protons from the water molecules, thus producing an excess of hydroxide (OH^-) ions in the solution. Such a solution is said to be alkaline.

The illustration in Figure 1.20 indicates the approximate pH values of various commonly used substances.

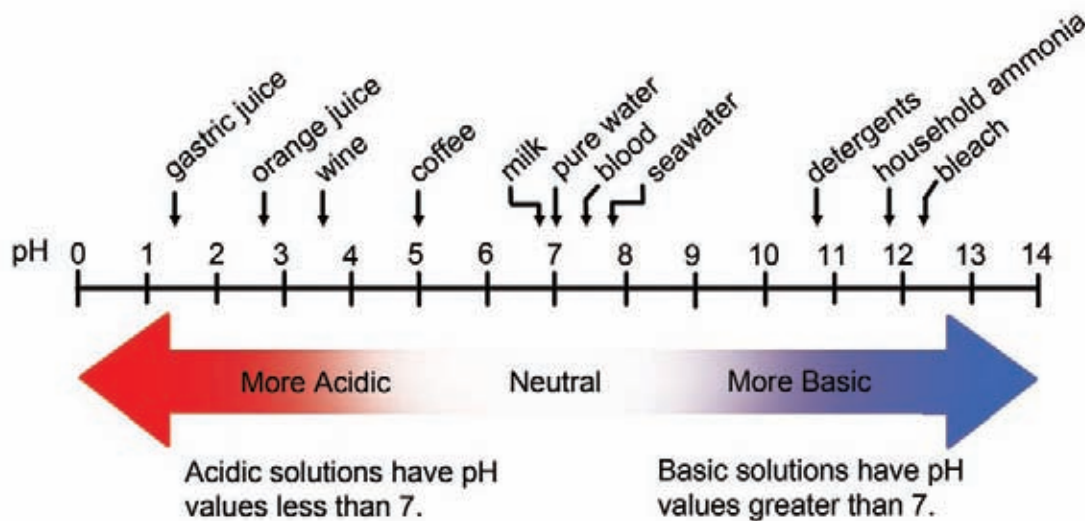


Figure 1.20: pH values of commonly used substances

The following table provides a comparison between acids and bases.

Acids	Bases
Excess hydronium ions (H_3O^+) Gives a proton to water Reacts with most metals to form hydrogen gas Frequently feels sticky Tastes sour (such as lemons) Usually a gas or liquid An acid has a pH less than 7 and contains the cation H^+	Excess hydroxide ions (OH^-) Accepts a proton from water Reacts with oils and greases Feels slippery Tastes bitter (such as baking soda) Frequently a solid (though ammonia is a gas that is usually dissolved in water) A base has a pH greater than 7 and contains the anion OH^-
Examples Hydrochloric acid – HCl Hydrosulphuric acid – H_2S Nitric acid – HNO_3 Sulphuric acid – H_2SO_4 Phosphoric acid – H_3PO_4 Carbonic acid – H_2CO_3 Acetic acid – $\text{HC}_2\text{H}_3\text{O}_2$ Boric acid – H_3BO_3	Examples Sodium hydroxide – NaOH Potassium hydroxide – KOH Ammonium hydroxide – NH_4OH Calcium hydroxide – $\text{Ca}(\text{OH})_2$ Barium hydroxide – $\text{Ba}(\text{OH})_2$ Hydroxide – $\text{Fe}(\text{OH})_2$ Hydroxide – $\text{Fe}(\text{OH})_3$ Zinc hydroxide – $\text{Zn}(\text{OH})_2$
Examples of common acids - citric acid (from citrus fruits) - ascorbic acid (vitamin C) - vinegar (5% acetic acid) - carbonic acid (for carbonation of soft drinks) - lactic acid (in buttermilk)	Examples of common bases - detergents - soap - caustic soda (NaOH) - household ammonia (aqueous)

Neutralisation

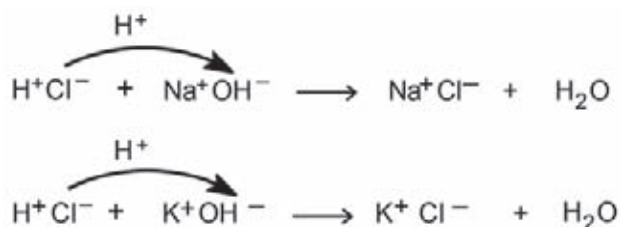


Figure 1.21: Examples of neutralisation

Neutralisation is the reaction between acids and bases. If an acid solution is mixed with an alkaline solution a chemical reaction takes place. If this reaction is controlled by adding the correct amounts of acid and alkali the solution will be rendered neutral.

Acid solutions will react with alkaline solutions to form water and salts. Figure 1.21 shows some common examples of neutralisation.



Figure 1.22: The neutralisation reaction

All neutralisation reactions between solutions of acids and alkalis can be represented by the following reaction as shown in Figure 1.22.

All the other ions remain present, but take no part in the reaction and are called 'spectator ions'. It is only the transfer of a proton from an acid to the OH^- ion of the alkali which has any effect on the final result.



Classroom activity 1

- 1 Fill in the missing word(s)
 - a) All matter consists of tiny particles, namely, _____.
 - b) All atoms contain _____ charged electrons.
 - c) An atom has a very small but very dense _____, which is _____ charged.
 - d) The nucleus consists of positively charged _____ and neutral particles, the _____.
 - e) An _____ cannot be decomposed into simpler substances.
- 2 Draw a table with four columns with the headings below, and list three examples of each.
 - a) alkali metals
 - b) alkaline earth metals
 - c) halogens
 - d) noble gases
- 3 Describe the development of an aqueous solutions of an:
 - a) acid
 - b) alkaline
- 4 From the periodic table in this unit, obtain the atomic number of the following atoms:
 - a) He
 - b) Mg
 - c) K
 - d) Ca
- 5 Draw Lewis structures for the following atoms:
 - a) sulphur
 - b) chloride
 - c) potassium
 - d) calcium

Homework activity 1

- 1 Complete the following sentences by filling in the missing words:
 - a) A _____ is made up of more than one element.
 - b) The number of protons in a nucleus of an atom is known as the _____ of that element.
 - c) The _____ in the nucleus of an atom is called the mass number.
 - d) The outer electrons of an atom are called the _____.
 - e) The electrons of an atom occur in different _____. The outermost electrons are called _____. The valence electrons take part in the formation of _____ with other atoms.

- f) In a chemical bonding different atoms will react with one another in order to fill the outer _____ with electrons, which is then a _____ configuration.
- g) Atoms can achieve _____ by the transfer of one or more electrons from one atom to the other, forming _____.
- h) _____ are the smallest particles of a substance which can exist independently and still _____ of that substance.
- i) A solution is an intimate _____ mixture of substances which are in the _____ phase.
- j) Mixtures and solutions differ from compounds in that the constituents of a mixture or a solution can be separated by _____, but not those of compounds.
- k) A single atom or a group of atoms can gain or lose _____ to become positively or negatively charged _____.

- 2 Why is it important to know the mass numbers of the elements?
- 3 Why would a system such as the periodic table be such an important tool for scientists? And for agriculturists?

Extra practice 1

- 1 Differentiate among the following particles of an atom:
 - a) proton
 - b) neutron
 - c) electron.
- 2 Explain the nature of isotopes.
- 3 Give two examples in nature of the following:
 - a) compound
 - b) mixture
 - c) solution.
- 4 Explain the difference between the halogens and the noble gases in the periodic table. Substantiate your explanation with two examples of each.
- 5 Show the reaction when an acid solution is formed and when an alkali solution is formed.
- 6 Analyse the general structure of an atom. Explain how this structure determines the behaviour of an element.
- 7 Use a drawing of a molecule of copper to explain the arrangement of electrons around the nucleus and the concept of valence electrons.



Summary

In this unit we learnt about:

- Basic chemistry terminology important in Agriculture: matter, atoms, molecules, ions, valency, isotopes, elements, compounds and mixtures
- The general structure of an atom
- The main types of particles of an atom and their respective charges
- The differences between elements, compounds and mixtures (with relevant examples)
- The basic interpretation of the periodic table of elements
- The arrangement of electrons around the nucleus and valency
- The relation between atomic numbers and number of particles in the nucleus
- The formation of ions
- Using the Lewis structures to illustrate the electron structure of an atom
- The differences between acids and bases.

Unit 2: Chemical bonding

What will you learn about in this unit?

- Basic chemical bonding as it occurs to form a molecule
- Chemical bonds with their respective structural formulae:
 - covalent bonding (hydrogen gas, water)
 - ionic bonding (copper chloride, sodium chloride).

Let's talk about this unit

A molecule is the smallest particle of a substance which can exist independently and still retain the properties of that substance. The simplest molecule is that of hydrogen (H_2), which is formed when two hydrogen atoms combine. It is an element because it contains only one kind of atom. A molecule of water (H_2O) consists of two hydrogen atoms and one oxygen atom. It contains more than one kind of atom therefore it is a compound.

What do I know already?



In Life Science Grade 10 you learnt about the molecules that are necessary for living organisms. You were introduced to organic compounds such as carbohydrates, lipids and proteins. You should remember that these compounds are bound together by carbon, hydrogen, oxygen and other atoms in chemical bonding.



- What is the main difference between a carbohydrate and a protein?
- Which field of study includes the reaction of acids with metals?
- Which field of study includes the carbohydrates, proteins and lipids?

Word bank



Chemical bonding: When two atoms combine with one another a chemical bond is formed

Covalent bonding: The bond pair (of electrons) is evenly shared between the two atoms, because the two nuclei attract the electron pair equally strongly

Electrostatic attraction: Attraction caused by different charges

Electrovalent: Attraction caused by electrons of different atoms

Interact: To act within close relativity

Ionic bonding: When atoms achieve full outer energy levels by the transfer of one or more electrons, two opposite charged atoms are attracted to one another to form an ionic bond

Overlap: Partly cover by extending beyond one edge

Polarity: State where there are two opposite poles of conflicting qualities.

What I still need to know



A basic chemical bonding as it occurs to form a molecule

In the H_2O molecule the bond pair (of electrons) is evenly shared between the two atoms, because the two nuclei attract the electron pair equally strongly. This is known as a covalent bond.

Water is one of the most effective solvents. In the water molecule the bonding is covalent. The water molecule gets a slight negative charge at the oxygen end, and the ends where the hydrogen atoms are get a slight positive charge. Such a molecule is known as a polar molecule, because it has a slightly negative pole (or end) and a slightly positive pole (or end), as Figure 1.23 shows.

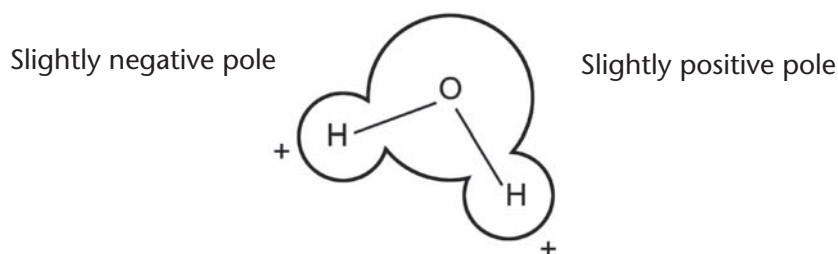


Figure 1.23: Water molecule

Covalent bonding

The sharing of pairs of electrons to form a covalent bond is a fairly common way of chemical bonding. Most of the normal compounds in everyday life are covalently bonded.

Covalent bonds are formed when atoms share a pair of bonding electrons, with the pair consisting of one electron from each atom. A covalent bond between two atoms therefore consists of a pair of electrons, one electron from each atom.

In the hydrogen molecule (H_2) the two atoms have their outer energy levels overlap one another to form a shared pair or bonding pair of electrons with one electron coming from each of the two atoms. Each atom now has a full outer shell with two electrons, $\text{H} + \text{H} \rightarrow \text{H}_2$, as shown in Figure 1.24.

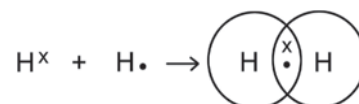


Figure 1.24: Lewis structure for the hydrogen molecule

As we can see from Figure 1.24, Lewis structures are often used to illustrate the bonding among different atoms in a compound.

In the water molecule (H_2O), two covalent bonds are formed between hydrogen and oxygen atoms, as Figure 1.25 shows.

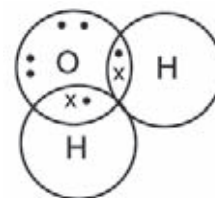


Figure 1.25: Lewis structure for the water molecule

Couper's structures to represent covalent bonds

Another way of representing covalent bonds is to use Couper's structures. In Couper's structures, each bond pair (that is, each pair of shared electrons) is indicated by a single line between the two atoms. This method is very handy for writing (or drawing) structural formulae.

	Formula	Structural Formula
Hydrogen	H ₂	H - H
Oxygen	O ₂	O = O
Water	H ₂ O	$\begin{array}{c} \text{H} - \text{O} \\ \\ \text{H} \end{array}$
Hydrogen chloride (gas)	HCl	H - Cl
Carbon dioxide	CO ₂	O = C = O
Ammonia	NH ₃	$\begin{array}{c} \text{H} \\ \\ \text{H} - \text{N} \\ \\ \text{H} \end{array}$
Methane	CH ₄	$\begin{array}{c} \text{H} \\ \\ \text{H} - \text{C} - \text{H} \\ \\ \text{H} \end{array}$

Figure 1.26: Couper's structure for molecules

Some examples of molecules and their structural formulae, using the Couper's structure, are shown in Figure 1.26.

Ionic bonding

Ionic bonds, in general, are represented by the alkali metals when they form alkaline solutions. Even the halogen group of elements has a tendency to form ionic bonds with other elements, for example sodium chloride (Na⁺ + Cl⁻).

In some cases atoms will achieve full outer energy levels by the transfer of one or more electrons from the one atom to the other. (This can happen when an atom containing one, two or three high energy valence electrons reacts with one needing only one or two electrons to fill the outer level.) The atom which loses one or more electrons becomes a positively charged ion (because it now has fewer electrons than protons), while the atom which gains one or more electrons becomes a negative ion. The two oppositely charged ions are now very strongly attracted to one another by electrostatic attraction. This is known as an ionic (or electrovalent) bond because it forms between two ions.

Example 1

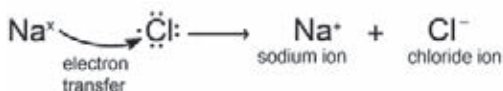


Figure 1.27: Ionic bond sodium chloride

As we have seen before, in the reaction between sodium and chlorine the two ions are now attracted to one another to form the ionic bond sodium chloride (with formula NaCl), as shown in Figure 1.27.

Water is a good solvent of ionic substances because of its polarity. For example, if common salt (NaCl) is dissolved in water, it will dissociate into Na⁺ and Cl⁻ ions. Each ion will be surrounded by a cluster of the polar water molecules. These ions are said to be hydrated, which means they are linked with water. Figure 1.28 shows this.

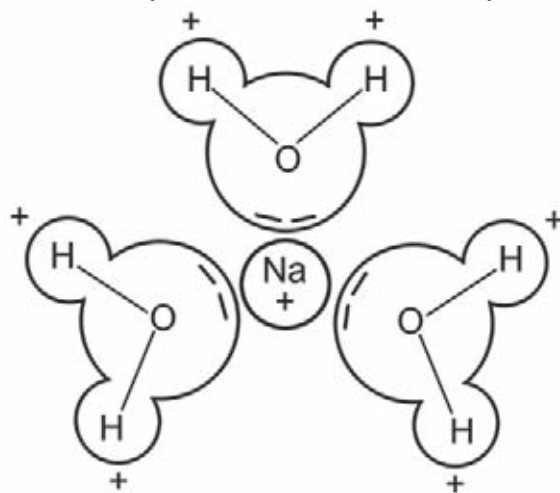


Figure 1.28a: Hydrated Na⁺ ion
 (The negative poles of the water molecules attract the positive Na⁺ ion)

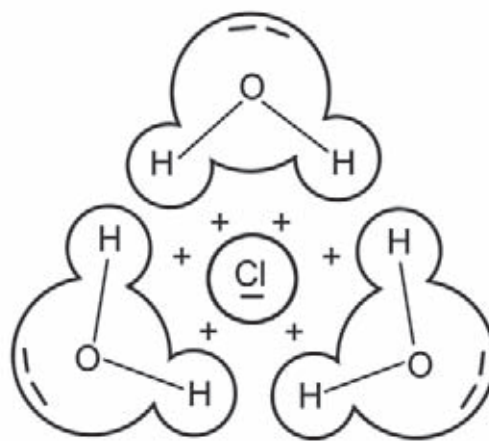


Figure 1.28b: Hydrated Cl⁻ ion
 (The positive poles of the water molecules attract the negative Cl⁻ ion)

In Figure 1.29, you can see how the electrons are transferred from the sodium atom to the chlorine atom to form the ionic bonds.

Both ions have full outside energy levels (like the noble gas atoms) and are stable, although they have now become electrically charged.

Sodium atom	:	Na	:	11 protons 11 electrons arranged 2, 8, 1
Chlorine atom	:	Cl	:	17 protons 17 electrons arranged 2, 8, 7
Now become:				
Sodium ion	:	Na	:	11 protons 10 electrons arranged 2, 8
Chloride ion	:	Cl	:	17 protons 18 electrons arranged 2, 8, 8

Figure 1.29: Table showing the electron transfer between sodium and chloride

Example 2

When copper reacts with hydrogen chloride (HCl), one copper ion Cu^+ and one chloride ion Cl^- are formed. These ions now attract one another to form the ionic compound, copper chloride (CuCl), as Figure 1.30 shows.

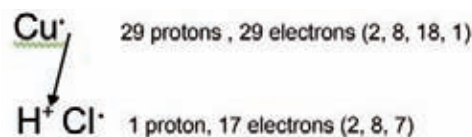


Figure 1.30: Copper reacting with hydrogen chloride (HCl)

Classroom activity 2

- 1 What is the name of the bond formed when the electron pair is equally strongly attracted to the nuclei of the two atoms involved in forming the bond?
- 2 Why is a water molecule slightly polar?
- 3 Why are helium and neon known as noble gases?
- 4 Are any other gases known as noble gases?
- 5 Analyse the Lewis structure below. Name the atoms that are involved in bonding and the resulting molecule. How many double bonds are formed?

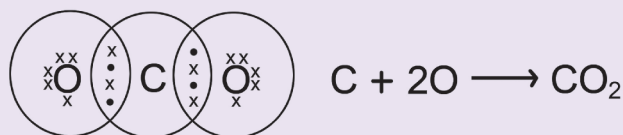


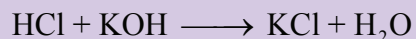
Figure 1.31

Homework activity 2

- 1 Sketch the Lewis structure of the water molecule and then answer the following questions:
 - a) Give the total number of electrons in the outer energy levels of the atoms which are bonded together to form this molecule.
 - b) What are the atomic numbers of the different atoms in this molecule?
 - c) Give the total number of electrons in *all* the energy levels of the atoms in this molecule.
- 2 Differentiate between covalent and ionic bonds by making use of the H_2O and NaCl molecules.

Extra practice 2

Study the following reaction between hydrochloric acid (HCl) and potassium hydroxide (KOH). Then answer the questions. Revise Unit 1 if you do not remember.



- 1 What do we call this kind of reaction and why?
- 2 What kind of bonds are involved in this reaction?

Summary

In this unit we learnt about:

- How basic chemical bonding occurs to form a molecule
- Chemical bonding with their respective structural formulae:
 - covalent bonding, for example hydrogen gas and water
 - ionic bonding, for example copper chloride and sodium chloride.



Unit 3: Inorganic and organic compounds

What will you learn about in this unit?

- The difference between inorganic and organic compounds (with examples)
- The chemical formulae, structural formulae, Lewis structures, importance and functions of the following inorganic compounds:
 - water
 - carbon dioxide
 - mineral salts, for example sodium chloride (table salt)
 - ammonia.
- The characteristics of the carbon atom (bonding on the carbon atom) and organic substances
- The basic structural formulae and chemical names of organic compounds.

Let's talk about this unit

Inorganic chemistry is the branch of chemistry concerned with the elements and all their compounds except those containing carbon (C). Organic chemistry is the branch of chemistry concerned with the compounds of carbon. The atmosphere contains a small but approximately constant proportion of carbon, in carbon dioxide. Carbon is an essential constituent of all living organisms. All living organisms obtain their supply of carbon from the air. In a complex natural reaction (photosynthesis) that takes place in the green leaves of plants, water combines with carbon dioxide to form glucose. The glucose molecule is essential for living organisms because it is the compound from which all other foodstuffs are derived.

What do I know already?



In Grade 10 you were introduced to the 'chemistry of life'. You learnt about minerals and water, which are the inorganic compounds essential for life. You also learnt about the sugars, proteins and fats, which are the organic compounds essential for life.

Check myself

- What food provides us with iodine?
- What is the main function of water in an animal's body?
- Which carbohydrate provides the main fuel for respiration?

Word bank

A B C

Ignited: To get started

Inorganic compounds: Inorganic compounds include salts, metals, substances made from single elements and any other compounds that do not contain carbon bonded to hydrogen

Organic compounds: Organic compounds, for example fats, sugars and proteins, always contain carbon in carbon-hydrogen or C-H bonds

Prefix: Letters that are added to the front of a word to change the word's meaning

Tetra-chloride: A four (tetra) combination of chloride atoms

Uniform: All the same

Valency quantum shell: The outermost shell of an atom, which determines its valency

Volatile: Liquid that easily changes into gas (vapour).

What I still need to know



Inorganic compounds versus organic compounds

Molecules and compounds can be classified as either organic or inorganic. Organic compounds and inorganic compounds form the basis for chemistry.

The main difference between organic compounds and inorganic compounds is that organic compounds always contain carbon, while most inorganic compounds do not contain carbon. Also, organic compounds contain carbon-hydrogen (C-H) bonds. The table which follows summarises the important differences between inorganic and organic compounds.

Inorganic compounds	Organic compounds
Inorganic compounds include salts, metals, substances made from single elements and any other compounds that do not contain carbon bonded to hydrogen: • table salt or sodium chloride, NaCl • carbon dioxide, CO₂ • diamond (pure carbon)	Organic compounds are molecules associated with living organisms. These include nucleic acids, fats, sugars, proteins, enzymes and many fuels. Organic compounds always contain carbon in carbon-hydrogen (C-H) bonds: • table sugar or sucrose, C₁₂H₂₂O₁₁ • benzene, C₆H₆ • methane, CH₄

A common mistake is to assume that the difference between inorganic and organic compounds is whether or not a substance contains carbon. Diamond is pure carbon, yet is inorganic. Carbon dioxide contains carbon and oxygen, both elements associated with life, yet it is an inorganic compound.

Inorganic compounds

Sub-group IV in the periodic table contains the elements carbon, silicon, tin and lead.

The chemical reactions between elements of sub-group IV in the periodic table are examples of **inorganic chemistry**, that is, the reactions of silicon, tin and lead with other elements in the periodic table. In fact all chemistry reactions among elements in the periodic table are inorganic, except for the chemical reactions between carbon and other elements.



The elements in sub-group IV (carbon, silicon, tin and lead) have the following characteristics:

- There are four electrons in the external energy level. The electron negativity of the sub-group IV elements decreases with the increase in atomic number.
- They differ much in physical and chemical properties, for example:
 - Carbon and silicon are non-metals with high melting points. Giant molecule crystals are formed
 - Tin and lead are metals with low melting points
 - Carbon and silicon are resistant to chemical attack, but tin and lead dissolve in acids and are oxidised if heated above room temperature.

The compounds of the four sub-group IV elements show graded chemical properties:

- Compounds formed with the element H:
 - CH_4 (methane) is the only stable compound
 - SiH_4 is decomposed by heat or by water
 - SnH_4 and PbH_4 are very unstable compounds.
- Compounds formed with the element Cl:
 - All tetra (four) chlorides are volatile substances, existing in the liquid state at room temperature.
- Compounds formed with the element O:

All four elements (of sub-group IV) form oxides with the oxygen element:

 - CO is neither acidic nor basic and is stable at room temperature
 - SiO is stable in the form of vapour
 - SnO is basic and inflames spontaneously in air
 - PbO is a stable basic oxide.

Carbon differs from silicon, tin and lead because it forms the enormous range of compounds that we study in **organic chemistry**. The ability of carbon to form numerous stable compounds is due to three properties of the carbon atom, which we will discuss later in this unit.

Inorganic compound – water

Water occurs in nature as water vapour in the atmosphere and as liquid water or ice (solid) in the ocean and inland waters. The purest form of natural water is rain water. Rain water falls onto the ground and percolates through the soil. Plants absorb the water from the soil, and through the process of photosynthesis they use water (with carbon dioxide) to form the glucose molecule, as shown by the reaction that follows.



Water is also used for drinking by all living organisms – animal and plant. Water sometimes needs to be softened for drinking, which means the removal of metallic salts and impurities from the water.

Water is also used for industries, and it is also sometimes necessary to soften (purify) the water before it can be used in boilers and laundries.

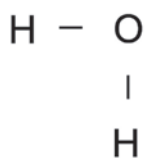


Figure 1.32:
Structural formula
of water

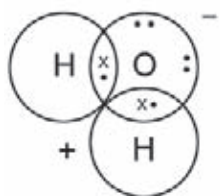


Figure 1.33: Lewis
structure of water

The functions and properties of water are listed below:

- The **melting point** of ice is 0°C and the **boiling point** of water is 100°C at sea level. The **density** of water at 4°C and the **volume** of one kilogram of water at 4°C is the standard litre.
- Pure water is almost a **non-conductor of electricity**.
- Water is a very powerful **solvent**, particularly for the electrovalent compounds, acids, bases and salts.
- Water is a **catalyst** in many chemical and physical changes. Substances which react readily in normal conditions fail to do so if dehydrated. This explains why the drying of food such as meat, fruit and vegetables prevents the food from becoming rotten.
- The chemical formula of water is H_2O . The structural formula is given in Figure 1.32.
- Water is the **hydride of oxygen** and each of the two O–H bonds is **polar**. This is because the O-atom attracts the bond more strongly than the H-atom. This gives the O-side of the molecule a slightly negative pole and the H-side a slightly positive pole. The **Lewis structure** is used to illustrate this, as shown in Figure 1.33.

Inorganic compound – carbon dioxide

The main source of the carbon in organic compounds is carbon dioxide in the air. Plants use sunlight to convert carbon dioxide into organic compounds through the process of photosynthesis. Plants are therefore able to make their own organic compounds through photosynthesis, while animals feed on plants or plant products so that they gain the organic compounds that they need to survive.

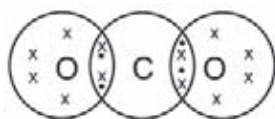


Figure 1.34: Lewis
structure of carbon
dioxide

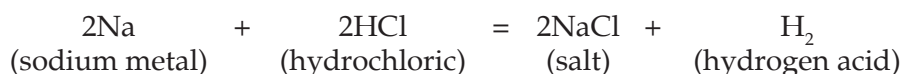
The functions and properties of carbon dioxide:

- It is a **tasteless, colourless, odourless gas**.
- It is **soluble in water** and it does not support the combustion of non-metals and is therefore used as a **fire extinguisher**.
- Carbon dioxide **does not support respiration**, but it is **not poisonous** to living organisms.
- The **chemical formula** of carbon dioxide is CO_2 and its **structural formula** is $\text{O} = \text{C} = \text{O}$.
- The **Lewis structure** of carbon dioxide shows two double bonds each consisting of two bond pairs, as given in Figure 1.34.

Inorganic compound – mineral salts

Sodium chloride (common table salt) is an inorganic compound (mineral salt). Sodium is one of the most abundant elements in nature. It is never found uncombined in nature because of its chemical activity. Soluble salts of sodium from weathered rocks and other sources find their way into the sea where the sodium accumulates as sodium chloride. Sea water contains 3.6% of dissolved solids of which three quarters is sodium chloride. Large deposits of sodium chloride, known as rock salt, are found in many places throughout the world.

Sodium reacts with chlorine to form sodium chloride. With acids, sodium reacts explosively to form the sodium salt of the acid with the liberation of hydrogen:



The functions and properties of sodium chloride:

- Sodium chloride is a transparent, crystalline solid.
- It is fully dissociated in a solution and gives all the reactions of sodium and chlorine ions.
- Sodium chloride is an essential constituent of foods to which it imparts a characteristic flavour. It is also used to preserve foods.
- In the earthenware industries it is used to salt-glaze the ware.
- The chemical formula of sodium chloride is NaCl and its structural formula is Na-Cl. The Lewis structure of sodium chloride shows the following reaction resulting in an ionic bond, as given in Figure 1.35.

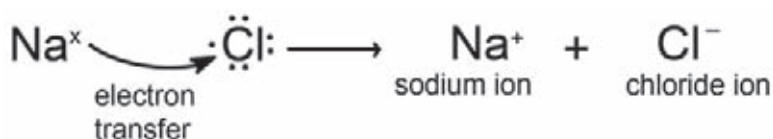


Figure 1.35: The Lewis structure of sodium chloride ionic bonding

Inorganic compound – ammonia

Ammonia (NH_3) is a compound of nitrogen and hydrogen. Ammonia is a colourless, pungent gas that is used in a wide variety of nitrogen-containing organic and inorganic chemicals. Ammonia is extensively used to manufacture fertilisers in the following ways:

- applied directly to soil from tanks of the liquefied gas.
- applied as salts of ammonia, such as ammonium phosphate and ammonium nitrate (the latter is also used in high explosives).
- ammonia has many other industrial uses as a raw material catalyst and alkali. It dissolves readily in water to form ammonium hydroxide, an alkaline solution which is used as a household cleaner.

Nitrogen occurs in the uncombined state in air. It is an essential constituent of all living organisms, both plants and animals. It is present in their tissues in compounds known as proteins (an organic compound).

Inorganic compounds in which the nitrogen atom exists are formed by three single covalent linkages. The nitrogen atom in ammonia is able to form a co-ionic link with a hydrogen ion as shown in Figure 1.36.

This reaction results in a positive ammonium ion, NH_4^+ which is present in ammonium salts.

The polarity of NH_3 molecules and their ability to form hydrogen bonds explains to some extent the high solubility of ammonia in water. However, a chemical reaction also occurs when ammonia dissolves in water – ammonia acts as a base, acquiring hydrogen ions from H_2O to yield ammonium and hydroxide ions, as shown in Figure 1.37.

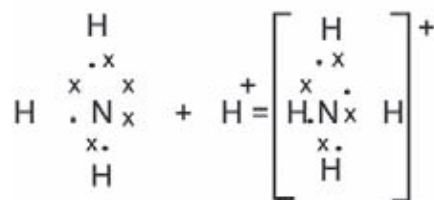


Figure 1.36: Nitrogen in ammonia forms a co-ionic link with a hydrogen ion



Figure 1.37: Ammonia dissolving in water

The functions and properties of ammonia:

- Ammonia is a **colourless gas** with a characteristic **smell**.
- Ammonia **does not burn in air**.
- Ammonia is **absorbed by acids** to form ammonium salts, for example $2\text{NH}_3 + \text{H}_2\text{SO}_4 \rightarrow (\text{NH}_4)_2\text{SO}_4$
- The **chemical formula** of ammonia is NH_3 and its structural formula is shown in Figure 1.38.
- The **Lewis structure** of the ammonium molecule shows three covalent links between one nitrogen and three hydrogen atoms, as Figure 1.39 shows.

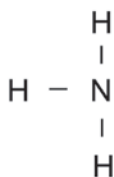


Figure 1.38: Structural formula for ammonia

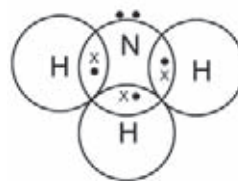


Figure 1.39: The Lewis structure for ammonia

Organic compounds

Organic compounds are very important in daily life. They make up a big part of our own bodies, they are in the food we eat and the clothes we wear. Living organisms consist mostly of water and organic compounds, including proteins, carbohydrates, fats, nucleic acids, hormones and vitamins. Natural and synthetic fibres and most fuels, drugs and plastics are organic compounds.

Organic chemistry is the study of carbon compounds (except for carbon dioxide, carbonates and bicarbonates). An organic molecule is one which contains carbon and these molecules can range in size from simple molecules to complex structures containing thousands of atoms.

Organic compounds have the following characteristics:

- They contain carbon bonds in which at least one carbon atom is covalently linked to an atom of another type, such as hydrogen (H), oxygen (O), nitrogen (N), sulphur (S) or phosphorus (P).
- The majority of organic compounds are compounds of carbon, hydrogen and oxygen.
- Hydrocarbons are compounds consisting of only carbon and hydrogen.
- Other important organic compounds contain the halogens (F, Cl, Br and I) and nitrogen.

The characteristics of the carbon atom

Carbon has a number of unique properties which influence how it behaves and how it bonds with other atoms. These characteristics form the basis of organic chemistry:

- Carbon has **four valence electrons** which means that each carbon atom can form four bonds with other atoms. Long chain structures can form. These chains can either be unbranched or branched, as shown in Figure 1.40.
- Compounds produced by the chemical combination of carbon (with H, O and Cl) are **equally stable**.

- Most of the bonds that carbon forms with other atoms are **covalent**, because of the position of carbon on the periodic table. For example, in a C-C bond the difference in electronegativity between the two atoms is zero, so this is a pure covalent bond. In the case of a C-H bond, the difference in electronegativity between carbon and hydrogen is so small that C-H bonds are almost purely covalent. Therefore most organic compounds are non-polar, which affects some of their properties.
- One, two or three **covalent bonds** may be established between two carbon atoms as in the case of ethane ($\text{H}_3\text{C}-\text{CH}_3$), ethylene ($\text{H}_2\text{C}=\text{CH}_2$) and acetylene ($\text{HC}\equiv\text{CH}$).
- The outer energy level (valence quantum shell) of a carbon atom exerting four covalent links contains the maximum number of **electrons**, namely eight, which are all **shared**. The carbon atom can therefore neither accept nor release electrons, so there is little opportunity for a chemical reaction.

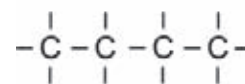


Figure 1.40a:
An unbranched carbon chain

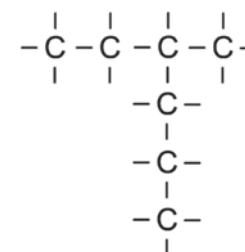


Figure 1.40b:
A branched carbon chain

Structural formulae of organic compounds

There are a number of ways to **represent organic compounds**. It is useful to know all of these so that you can recognise a molecule however it is shown. There are three main ways of representing a compound. In Figure 1.41, we will use the example of a molecule of 2-methylpropane to help explain the differences.

Method of representation	Example: 2-methylpropane compound
The molecular formula of an organic compound shows how many atoms of each type are in a molecule. The number of each atom is written as a subscript after the atomic symbol.	C_4H_{10}
The structural formula of an organic compound shows every bond between every atom in the molecule. Each bond is represented by a line.	$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{H} \quad \quad \text{H} \\ \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$
When a compound is represented using its condensed structural formula, each carbon atom and the hydrogen atoms that are bonded directly to it are listed as a molecular formula, followed by a similar molecular formula for the neighbouring carbon atom. Branched groups are shown in brackets after the carbon atom to which they are bonded.	$\text{CH}_3\text{CH}(\text{CH}_3)\text{CH}_3$

Figure 1.41: Three ways to represent organic compounds

All organic compounds have a particular bond or group of atoms which we call its functional group. This group is important in determining how a compound will react. In organic chemistry, a functional group is a specific group of atoms within molecules that are responsible for the characteristic chemical reactions of those molecules. The same functional group will undergo the same or similar chemical reaction(s) regardless of the size of the molecule that it is a part of:

- In one group of organic compounds called the hydrocarbons, the single, double and triple bonds of the alkanes, alkenes and alkynes are examples of functional groups.
- In another group, the alcohols, an oxygen and a hydrogen atom are bonded to each other to form the functional group for those compounds (in other words an alcohol has an OH in it). All alcohols will contain an oxygen and a hydrogen atom bonded together in some part of the molecule.

The table shown in Figure 1.42 provides a summary of the main functional groups of organic compounds.

Name of group	Functional group	Example	Structural formula
Alkane		Ethane	
Alkene		Ethene	
Alkyne		Ethyne (acetylene)	
Halo-alkane X = F, Cl, Br, I		Chloroethane	
Alcohol/alkanol		Ethanol	
Carboxylic acid		Ethanoic acid	
Amine		Glycine	

Figure 1.42: Main functional groups of organic compounds



We will explore these functional groups of organic compounds further in specific units later in this Topic.

Chemical names of organic compounds

There are rules for naming organic compounds. When naming organic compounds, the IUPAC (International Union of Pure and Applied Chemistry) nomenclature is used. The following steps help us to do so.

Step 1: Recognise the functional group in the compound

This will determine the suffix (the 'end') of the name. For example, if the compound is an alkane, the suffix will be -ane; if the compound is an alkene the suffix will be -ene; if the compound is an alcohol the suffix will be -ol, and so on.

Step 2: Count the number of carbon atoms in the chain

Find the longest continuous carbon chain and count the number of carbon atoms in this chain. This number will determine the prefix (the 'beginning') of the compound's name.

Using the convention C_n to denote a straight chain of n atoms, the prefixes for chain lengths from one to ten are given here:

C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
meth-	eth-	prop-	but-	pent-	hex-	hept-	oct-	non-	dec-

Step 3: Number the carbon bonds

Number the carbons in the longest carbon chain. (Important: If there is a double or triple bond, you need to start numbering so that the bond is at the carbon with the lowest number.)

Step 4: Name the branches

Look for any branched groups and name them. Also give them a number to show their position on the carbon chain. If there are no branched groups, this step can be left out.

Step 5: Combine the elements of the name into a single word

Combine the elements of the name into a single word in the following order: branched groups; prefix; name ending according to the functional group and its position along the longest carbon chain.

Figure 1.43 provides two examples of how to name an organic compound.

Steps	Example 1	Example 2
Step 1: Recognise the functional group in the compound.	The compound is a hydrocarbon with single bonds between the carbon atoms. It is an alkane and will have a suffix of -ane.	The compound is an alkane and will have the suffix -ane.
Step 2: Count the number of carbon atoms in the chain.	There are four carbon atoms in the longest chain. The prefix of the compound will be 'but-'.	There are three carbons in the longest chain. The prefix for this compound is 'prop-'.
Step 3: Number the carbon bonds.	The carbons are numbered from left to right, from one to four.	If we start at the carbon on the left, we can number the atoms.
Step 4: Name the branches.	There are no branched groups in this compound.	There is a branched group attached to the second carbon atom. This group has the formula CH_3 which is methane. However, because it is not part of the main chain, it is given the suffix -yl (i.e. methyl).
Step 5: Combine the elements of the name into a single word.	The name of the compound is butane .	The compound's name is 2-methylpropane .

Figure 1.43: Chemical names of organic compounds

Some more examples of the structural and molecular formulas of organic compounds follow.

Alkanes

The alkanes are hydrocarbons which only contain single covalent bonds between their carbon atoms. This means that they are saturated compounds and are quite unreactive.

All alkanes have the same general formula: $\text{C}_n\text{H}_{2n+2}$

So an alkane with eight carbons must have $(2 \times 8) + 2$ hydrogens = C_8H_{18}

Figure 1.44 shows the structural and molecular formulae of four alkanes.

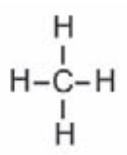
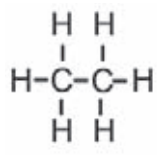
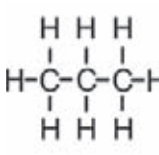
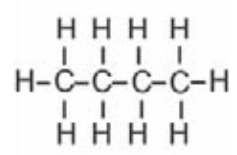
Methane	Ethane	Propane	Butane
			
CH_4	C_2H_6	C_3H_8	C_4H_{10}

Figure 1.44: Alkanes: structural and molecular formulae

Note: Alkenes and alkynes are not important to the study of Agricultural Science and are therefore not covered here.

Alcohols

An alcohol is any organic compound where there is a hydroxyl functional group (-OH) bound to a carbon atom. The general formula for a simple alcohol is $C_nH_{2n+1}OH$. All alcohol names end in -ol (or -anol). The simplest and most commonly used alcohols are methanol and ethanol, which are shown in Figure 1.45.

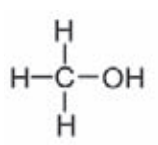
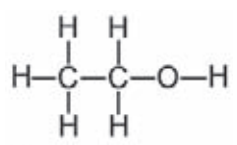
Methanol	Ethanol
	
CH_3OH	C_2H_5OH

Figure 1.45: Alcohols: structural and molecular formulae

Carboxylic (or fatty) acids

Carboxylic acids are organic acids which are characterised by having a carboxyl group, which has the formula -COOH. In a carboxyl group, an oxygen atom is double-bonded to a carbon atom, which is also bonded to a hydroxyl group. The simplest carboxylic acid is methanoic acid. Figure 1.46 shows the structural and molecular formulae of two carboxylic acids.

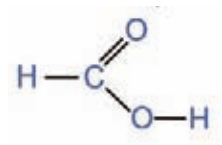
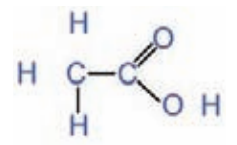
Methanoic acid (formic acid)	Ethanoic acid (acetic acid)
	
$HCOOH$	CH_3COOH

Figure 1.46: Carboxylic (or fatty) acids: structural and molecular formulae

Methanoic acid is found in insect stings. Ethanoic acid (CH_3COOH), or acetic acid, is the main component of vinegar. More complex organic acids also have a variety of different functions, for example benzoic acid ($\text{C}_6\text{H}_5\text{COOH}$) is used as a food preservative.

The amino group

The amino group has the formula $-\text{NH}_2$ and consists of a nitrogen atom that is bonded to two hydrogen atoms, and to the carbon skeleton. Organic compounds that contain this functional group are called amines. Glycine is an example of an amine. It belongs to a group of organic compounds called amino acids, which are the building blocks of proteins. Figure 1.47 shows the structural and molecular formula of glycine.

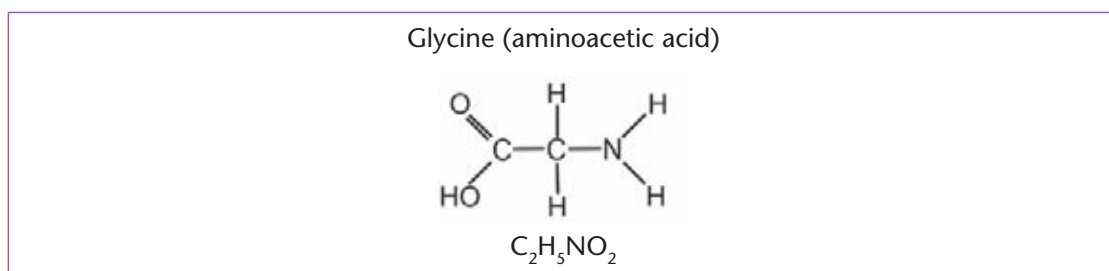


Figure 1.47: The amino group: structural and molecular formulae

The carbonyl group

The carbonyl group ($-\text{CO}$) consists of a carbon atom that is joined to an oxygen by a double bond.

The ketones are a group of compounds that contain a carbonyl group, which consists of an oxygen atom that is double-bonded to a carbon atom. In a ketone, the carbonyl group is on the end of the carbon chain. The simplest ketone is acetone, which contains three carbon atoms. A ketone has the ending 'one' in its IUPAC name. There are many ketones, and some are very importance in industry, for example the industrial solvent acetone (Figure 1.48), and in biology, for example sugars.

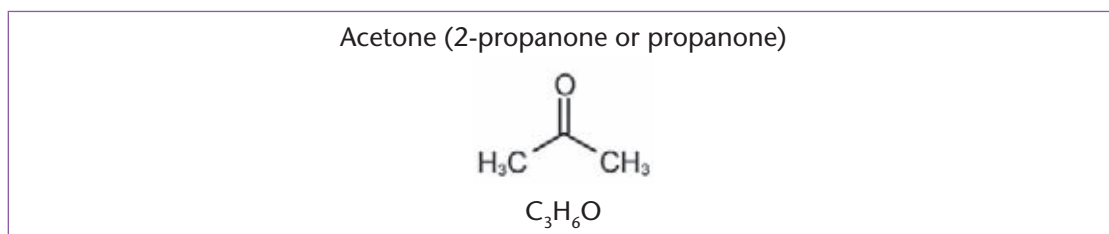


Figure 1.48: The carbonyl group: ketones: structural and molecular formulae

Carbohydrates include the sugars and their polymers. One key characteristic of the carbohydrates is that they contain only the elements carbon, hydrogen and oxygen. In the carbohydrate monomers, every carbon except one has a hydroxyl group attached to it, and the remaining carbon atom is double bonded to an oxygen atom to form a carbonyl group. One of the most important monomers in the carbohydrates is glucose. The glucose molecule can exist in an open-chain (acyclic) and ring (cyclic) form.

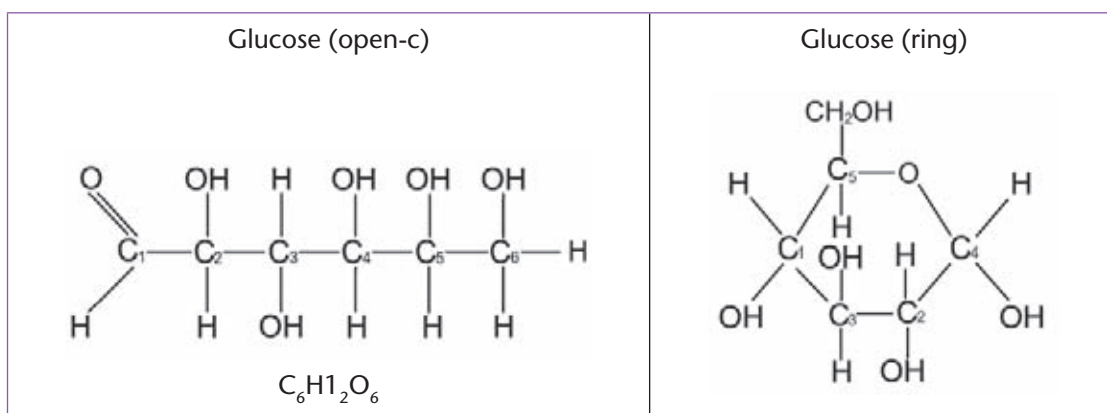


Figure 1.49: The carbonyl group: carbohydrates: structural and molecular formulae

Glucose is produced during photosynthesis, which takes place in plants. During photosynthesis, sunlight (solar energy), water and carbon dioxide are involved in a chemical reaction that produces glucose and oxygen.

Classroom activity 3

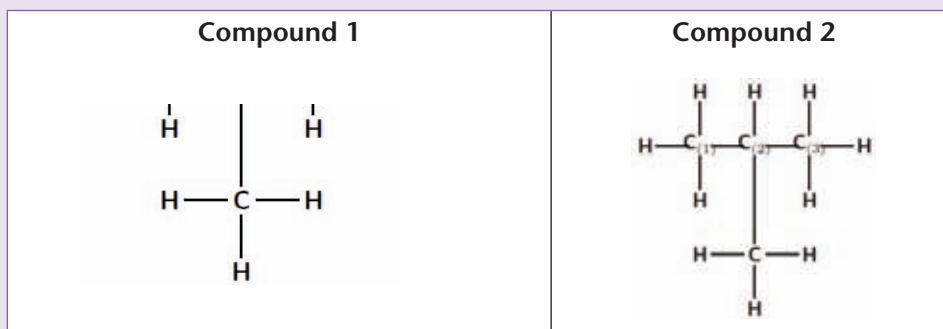
- 1 Explain the main difference between the field of inorganic chemistry and the field of organic chemistry.
- 2 Discuss the characteristics of the elements in sub-group IV: Carbon, silicon, tin and lead.
- 3 Give the properties of the following compounds formed with elements of sub-group IV:
 - a) SiH_4
 - b) CO_2
 - c) SnO
 - d) CH_4
- 4 Which of the compounds mentioned in question 3 belongs to organic chemistry?
- 5 Use the format below to compare the different inorganic compounds with one another:

Characteristics	Water	Carbon-dioxide	Sodium chloride	Ammonia
Chemical formulae				
One use of each				

- 6 Give four examples of alkanes.

Homework activity 3

- 1** Describe the five steps that we use to name an organic compound. Use these five steps to name the two compounds in the table below:



- 2 Discuss the importance of the following inorganic compounds for life on earth
 - a) water
 - b) carbon dioxide
- 3 Explain in detail the properties of the carbon atom that form the basis of organic chemistry.

Extra practice 3

- 1** Draw the structural formulae of the following organic compounds:
- | | |
|------------|-----------|
| a) propane | b) ethane |
| c) propane | d) butane |

Summary

In this unit we learnt about:

- The difference between inorganic and organic compounds (with examples)
- The chemical formulae, structural formulae, Lewis structures, importance and functions of the following inorganic compounds:
 - water
 - carbon dioxide
 - mineral salts, for example sodium chloride/table salt
 - ammonia
- The characteristics of the carbon atom (bonding on the carbon atom) and organic substances
- The basic structural formulae and chemical names of organic compounds.



Unit 4: Alkanes and alcohols

What will you learn about in this unit?

- Alkanes, including:
 - the basic types of alkanes (not more than five carbon atoms)
 - their chemical and structural formulae
 - their importance in plants and animal metabolism
 - the concept of isomers as illustrated by simple alkane structures
- Comparisons between alcohols and alkanes based on their general structural formulae
- The basic types of alcohols (their structures and importance) with reference to methanol and ethanol.

Let's talk about this unit

Hydrocarbons are organic compounds which contain only carbon and hydrogen. Alkanes and alcohols are both hydrocarbons.

The main differences between alkanes and alcohols:

- Alcohol (or ethanol) has a hydroxyl (OH) group on the end of its carbon chain, and contains no double bonds.
- Alkanes are also a single chain of carbon atoms joined by single bonds, but do not have an OH group attached to them.

The alcohols are a very important group of organic compounds, and they have a variety of uses. Our most common use of the word 'alcohol' is with reference to alcoholic drinks. The alcohol in alcoholic drinks is in fact ethanol. But ethanol has many more uses apart from alcoholic drinks! When ethanol burns in air, it produces carbon dioxide, water and energy and can therefore be used as a fuel on its own, or in mixtures with petrol. Ethanol can be produced through fermentation, which is a useful way for countries without an oil industry to reduce imports of petrol. Ethanol is also used as a solvent in many perfumes and cosmetics.

The alkanes are a very important source of fuel throughout the world and are used extensively in the chemical industry. Some are gases, for example methane and ethane, while others are liquid fuels, for example octane, an important component of petrol.

What do I know already?



In Grade 10 you were introduced to the process of photosynthesis and cellular respiration. You learnt about food and diet as well as different nutritional choices.



- What happens to the glucose that plants produce during photosynthesis?
- What is meant by the term 'aerobic respiration'?

Word bank

Double-bonded: Two sets of valence electrons, one from each atom, cause the bonding of atoms

Enzyme: Acts as a catalyst

Fermentation: Breaking down of organic material by bacteria

Hydrocarbons: Carbon atom with hydrogen atoms attached to it

Hydrogen: An H-atom

Hydroxyl: An OH⁻ ion

Intestine: Part of the alimentary canal of an animal

Isomers: Atoms with the same molecular formula but with different structures

Methane-generating: The production of methane through a process

Methanogen: Organism (microbe) which produces methane gas from organic matter

Uniform system: System which is the same as others.

What I still need to know

Alkanes

Alkanes are hydrocarbons ranging from one carbon atom per molecule to chains containing sixty or more carbon atoms. Alkanes differ from the other hydrocarbons because each carbon atom is joined to the next carbon atom by a single bond, that is, all carbon-to-carbon bonds are single bonds (C-C). The alkanes are sometimes also known as the paraffins.

The basic types of alkanes and their structural formulae

Figure 1.50 shows four different alkanes with their molecular, structural and condensed structural formulae.

Methane	Ethane
Methane is a gas often found in mines, especially coal mines. The gas is odourless and colourless and consists of molecules which contain one carbon atom and four hydrogen atoms.	Ethane is a colourless, odourless gas.
<i>Molecular formula</i>	<i>Molecular formula</i>
CH ₄	C ₂ H ₆
<i>Structural formula</i>	<i>Structural formula</i>
$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{H} \end{array}$	$\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array}$
<i>Condensed structural formula</i>	<i>Condensed structural formula</i>
CH ₄	CH ₃ .CH ₃



Propane	Butane
Propane is a colourless, odourless gas obtained when one hydrogen atom of ethane is replaced by a methyl group.	Butane is a colourless and odourless gas and is formed when a hydrogen atom of propane is replaced by a methyl group.
Molecular formula C_3H_8	Molecular formula C_4H_{10}
Structural formula $ \begin{array}{c} H & H & H \\ & & \\ H-C & -C & -C-H \\ & & \\ H & H & H \end{array} $	Structural formula $ \begin{array}{c} H & H & H & H \\ & & & \\ H-C & -C & -C & -C-H \\ & & & \\ H & H & H & H \end{array} $
Condensed structural formula $CH_3 \cdot CH_2 \cdot CH_3$	Condensed structural formula $CH_3 \cdot CH_2 \cdot CH_2 \cdot CH_3$ or $CH_3 \cdot (CH_2)_2 \cdot CH_3$

Figure 1.50: Molecular, structural and condensed structural formulae for alkanes

Butane differs from the previous three gases (methane, ethane and propane), in that they have only one possible structural formula. Butane, however, has two different possibilities of bonding. It therefore also has two different structures, although they have the same molecular formula. The different structural forms of the same compound are known as isomers.

Note the following:

The names of all alkanes end in ‘-ane’:

- A uniform system is used to name the number of carbon atoms in the longest (main) chain by a standard prefix:
 - One carbon: meth-
 - Two carbons: eth-
 - Three carbons: prop-
 - Four carbons: but-
 - Five carbons: pent-
- All alkanes have the same general formula: C_nH_{2n+2}
For example, an alkane with eight carbons must have $(2 \times 8) +$ two hydrogens, C_8H_{18} , and so on.

Importance of alkanes in plants and animal metabolism

Methane-generating bacteria are found in the gut of ruminants such as cattle and sheep. Methane (CH_4) is a by-product of these bacteria when they decompose the food (organic matter) in the gut of ruminants. Methane is formed in this environment where there is little free oxygen.

Metabolism by methanogens (microbes)

The methane output of cattle and other ruminants is due to methanogens. Up to one and a half litres of methane gas is released per day. This takes place through the metabolism of carbon dioxide (or other oxidised organic compounds). The energy is released by the oxidation of hydrogens, as shown in Figure 1.51.



Figure 1.51: Metabolism of carbon dioxide

This release of methane gas is at the end of the carbon cycle with carbon being released back into the atmosphere – after being fixed by photosynthesis in the green plants, at the beginning of the carbon cycle.

Importance of alkanes in plant metabolism

Alkanes play a minor role in the metabolism of most living organisms. In plants, the solid long-chain alkanes are found. These alkanes form a firm layer of wax (cuticle) over areas of the plant which are exposed to air. This is the plant's way of limiting water losses. The cuticle also prevents the leaking of important plant minerals (nutrients) by rain, and provides protection against bacteria, fungi and harmful insects.

The shiny layer on the skins of fruits such as apples and plums consists of long-chain alkanes. These carbon chains are between twenty and thirty carbon atoms in length and are made by the plant from fatty acids.

The waxy layer of plants changes with the season, where environmental conditions like light, temperature and humidity have an influence on the thickness of the layer.

Importance of alkanes in animal metabolism

Alkanes are found in animal products like shark liver oil. Alkanes occur in certain chemical messenger materials which insects use for communication. The alkanes have a distinct smell, which is a useful characteristic for pest control.

Methane-generating bacteria are found in the gut of cattle. As we mentioned earlier, methane (CH_4) is a by-product of these bacteria when they decompose food eaten by the cattle.

Alkanes in the metabolism of plants and animals in an ecological relationship

The relationship between sand bees and the early spider orchid is dependent on alkanes. The sand bees use alkanes in order to identify a mate. The female emits a mixture of alkanes and the mates are attracted by the odour. The orchid takes advantage of this mating arrangement to get the male bee to collect and disseminate its pollen. The flower of the orchid produces large quantities of the three alkanes in the same ratio as the female sand bees. The alkanes lure numerous male sand bees to the bloom in an attempt to copulate with their imaginary mate (partner). This allows the orchid to transfer its pollen.

Isomers in simple alkane structures

The spacial orientation of the atoms (of carbons and hydrogens) in an organic compound (molecule) can differ. This difference results in the formation of the isomers of the organic compound.

Isomers contribute to the diversity of organic molecules. The word 'isomere' means 'equal parts'. In the context of organic chemistry, isomers refer to molecules that have identical molecular formulae because they have the same number and kinds of atoms. However, they are different molecules because the atoms in each isomer are arranged differently.



Examples of isomers are the compounds glyceraldehyde and dihydroxyacetone. Both of these compounds have the formula $C_3H_6O_3$. In the case of glyceraldehyde the oxygen atom is double-bonded to an end-carbon. In the case of dihydroxyacetone the oxygen is double-bonded to the middle carbon. Figure 1.52 shows these two isomers.

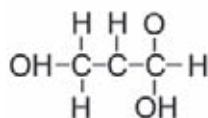


Figure 1.52a: Glyceraldehyde

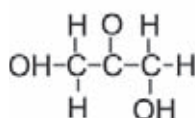


Figure 1.52b: Dihydroxyacetone

In the case of alkanes, isomers also occur. Two isomers occur with the alkane, butane, as you can see in Figure 1.53. Apart from the normal alkane, butane, there also exists the isomer of butane, methyl propane. This isomer is also known as isobutane. However we do not use this name anymore because we always name the longest carbon chain last. In this case it is the three-carbon chain, propane. The side chain is named first, as methyl side chain or group.

Butane structural formula	Isomer structural formula – methyl propane
$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$ $\text{CH}_3 \cdot \text{CH}_2 \cdot \text{CH}_2 \cdot \text{CH}_3$ or $\text{CH}_3 \cdot (\text{CH}_2)_2 \cdot \text{CH}_3$	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{H} \end{array}$ $\text{CH}_3 \cdot \text{CH}(\text{CH}_3) \cdot \text{CH}_3$

Figure 1.53: Butane isomer – methyl propane

Comparison of the general structures of alkanes and alcohols

In this unit we have explored alkanes and alcohols. The following points are important:

- The alkanes consist of carbon and hydrogen atoms only. The alcohols differ from the alkanes in that one hydrogen atom is replaced with a hydroxyl group (-OH).
- All alcohols contain only one -OH per molecule and are therefore known as monohydric alcohols.

Figure 1.54 shows how alkanes and alcohols have related chemical structures.

	Methane	Ethane	Propane	Butane
Alkanes	$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{H} \end{array}$ CH_4	$\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array}$ C_2H_6	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$ C_3H_8	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$ C_4H_{10}

Alcohols	Methanol	Ethanol	Propanol	Butanol
	$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{OH} \\ \\ \text{H} \end{array}$ $\text{CH}_3\cdot\text{OH}$	$\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{OH} \\ \quad \\ \text{H} \quad \text{H} \end{array}$ $\text{C}_2\cdot\text{H}_5\cdot\text{OH}$	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{OH} \\ \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$ $\text{C}_3\cdot\text{H}_7\cdot\text{OH}$	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{O} \cdot \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$ $\text{C}_4\cdot\text{H}_9\cdot\text{OH}$

Figure 1.54: General structures of alkanes and alcohols

Alcohols

There are many different types of alcohols. The proper name for alcohol is alkanol. Alcohols can be regarded as alkanes in which one hydrogen atom has been replaced by a hydroxyl (-OH) group. This hydroxyl (-OH) group is called the functional group and is the essential part of all alcohols. All alcohol names end in -ol (or -anol). The number of carbon atoms in the chain is named as before.

The simplest and most commonly used alcohols are methanol and ethanol.

The basic types of alcohols and their structural formulae

Figure 1.55 shows alcohols with their molecular formula, structural formula and condensed structural formula.

Methanol	Ethanol
Methanol is an extremely poisonous liquid. It is used as a solvent and as methylated spirits for heating or cooking. It can cause blindness when consumed by humans. <i>Molecular formula</i> CH_3OH <i>Structural formula</i> $\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{OH} \\ \\ \text{H} \end{array}$ <i>Condensed structural formula</i> CH_3OH	Ethanol is what we know as alcohol. This alcohol is found in all alcoholic drinks. It is formed by a fermentation process. <i>Molecular formula</i> $\text{C}_2\text{H}_5\text{OH}$ <i>Structural formula</i> $\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{OH} \\ \quad \\ \text{H} \quad \text{H} \end{array}$ <i>Condensed structural formula</i> $\text{CH}_3\text{CH}_2\text{OH}$

Figure 1.55: Basic types of alcohols and their structural formulae

Ethanol is formed by a fermentation process which is caused by micro-organisms that produce the enzymes which will cause the chemical reaction to form alcohol. The final reaction, whatever the starting point, is shown in Figure 1.56.

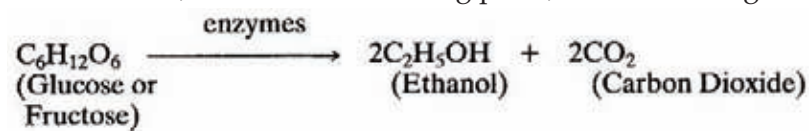


Figure 1.56: Fermentation



The carbon dioxide which is released during fermentation gives the impression that the fermenting mass is boiling, hence the word fermentation, which means boiling.

When all the sugars have been used up and the ethanol is further exposed to the air, it will also be further exposed to another enzyme which is secreted by acetobacter bacteria. In this reaction the ethanol is oxidised to ethanoic acid (vinegar), as Figure 1.57 shows.

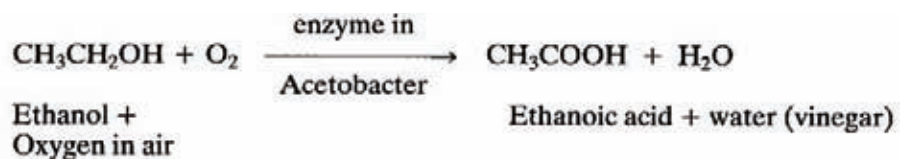


Figure 1.57: Oxidation of ethanol to ethanoic acid (vinegar)

The importance of alcohols

- Ethanol is found in all alcoholic drinks.
- Ethanol is used with sulphuric acid to prepare ethylene which burns in air to form water (H_2O) and carbon dioxide (CO_2).
- Methanol is used as methylated spirits for heating and cooking.
- Glycerol is the building block of all fats.

Isomers in simple alcohol structures

As with alkanes there are also **isomers for alcohols**, such as propanol. An isomer of propanol can form when the -OH attaches to the middle C-atom.

We then need to give it a special name. We number the C-atoms from the end nearest to the -OH and we say where the OH (or -OL) is attached.

The structural formulae for propanol and its isomers are given in Figure 1.58.

Isomer Propan-1-ol (or 1-propanol)	Isomer Propan-2-ol (or 2-propanol)	Isomer Propan-1,2,3-triol
$\begin{array}{ccccccc} & \text{H} & & \text{H} & & \text{H} & & \text{H} \\ & & & & & & & \\ \text{H} & - \text{C} & - & \text{C} & - & \text{C} & - & \text{C} - \text{OH} \\ & & & & & & & \\ & \text{H} & & \text{H} & & \text{H} & & \text{H} \end{array}$ $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$ or $\text{C}_3\text{H}_7\text{OH}$	$\begin{array}{ccccccc} & \text{H} & & \text{H} & & \text{H} \\ & & & & & \\ \text{H} & - \text{C} & - & \text{C} & - & \text{C} - \text{H} \\ & & & & & \\ & \text{H} & & \text{OH} & & \text{H} \end{array}$ $\text{CH}_3\text{CH}(\text{OH})\text{CH}_3$	$\begin{array}{ccccccc} & \text{H} & & \text{H} & & \text{H} \\ & & & & & \\ \text{H} & - \text{C} & - & \text{C} & - & \text{C} - \text{H} \\ & & & & & \\ & \text{OH} & & \text{OH} & & \text{OH} \end{array}$ $\text{CH}_2\text{OH}.\text{CHOH}.\text{CH}_2\text{OH}$

Figure 1.58: Structural formulae for propanol and its isomers

The third isomer, propan-1,2,3-triol (commonly known as glycerol), is a trihydric alcohol.

If an alcohol molecule has two -OH groups it is a dihydric alcohol, three -OH groups a trihydric alcohol, and so on.

Classroom activity 4

- 1 Explain in your own words what an isomer is. Give an example of two isomers that you have learnt about.
- 2 Study the following structural formula of an organic compound and answer the questions below:

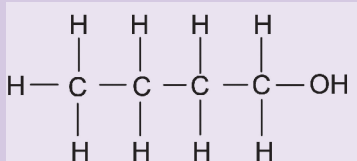


Figure 1.59: An organic compound

- a) Identify this compound.
- b) What type of bond exists between the carbon atoms?
- c) Give the functional group of this compound.
- d) Name the other two isomers of this compound that you have studied.

Homework activity 4

- 1 Name and list four alkanes and four alcohols.
- 2 Create a table comparing alkanes with alcohols.
- 3 Describe why alkanes are important in plants and animal metabolism.
- 4 Describe what an isomer is and give an example of an alkane and an alcohol isomer.
- 5 Describe the commercial uses of ethanol.

Extra practice 4

- 1 Complete the following table by providing the chemical formulae and structural formulae of the alkanes and alcohols that we have studied:

Alkanes	No of Carbon Atoms	Chemical Formula	Structural Formula
methane			
ethane			
propane			
butane			
Alkanes	No of Carbon Atoms	Chemical Formula	Structural Formula
methanol			
ethanol			



Summary

In this unit we have learnt about:

- Alkanes
 - the basic types of alkanes (not more than five carbon atoms)
 - their chemical and structural formulae
 - their importance in plants and animal metabolism
 - the concept of isomers as illustrated by simple alkane structures
- Comparison between alcohols and alkanes based on their general structural formulae
- The basic types of alcohols (their structures and importance) with reference to methanol and ethanol.

Unit 5: Fatty acids and bio-molecules (lipids/fats)

What will you learn about in this unit?

- Fatty acids:
 - the chemical structure of a simple fatty acid
 - the difference between saturated and unsaturated fatty acids (their structures and importance)
 - the differences between fatty acids and alcohols based on their structural formulae
- Bio-molecules (lipids):
 - basic composition of a simple lipid / fat
 - the differences between fats and oils, and saturated and unsaturated fats
 - the main functions of lipids/fats in living organisms.

Let's talk about this unit

In order to keep our bodies healthy, we should eat a balanced diet with the right amounts of carbohydrates, proteins and fats. Fats are an important source of energy, they provide insulation for the body, and they also provide a protective layer around many vital organs.

A biological macromolecule is a molecule that is found in living organisms. Biological macromolecules include molecules such as carbohydrates, proteins and nucleic acids. Lipids/fats are also biological macromolecules. They are essential for almost all living organisms.

Lipids include:

- various biomolecules, which are all insoluble in water
- a variety of molecular types, such as neutral fats, oils, steroids and waxes.

Lipids perform many important functions in biological systems, such as:

- contributing to the structure of membranes that enclose cells and cell compartments
- protecting against desiccation (drying out)
- storing concentrated energy
- insulating against cold
- absorbing shocks
- regulating cell activities by hormone actions.

Steroids have two main functions:

- they act as hormones, such as the sex hormones estrogen and testosterone
- they form structural material such as cholesterol, which is an important part of animal cell membranes.

What do I know already?



In Grade 10 you studied nutrition and diet. You learnt that carbohydrates and fats are our major sources of energy, and that the energy value of fats is 39 kilojoules per gram.

You also learnt about fatty acids. These fatty acids have to combine with a suitable alcohol (glycerol) to form the product that we call fat. Remember that butter is also a fat but it is called butter because of its unique characteristics.

Check myself

- Name the foodstuffs that you eat daily.
- Name those foodstuffs that are rich in fat.
- People talk about saturated and unsaturated fats. One type is healthier for humans than the other – or so the advertisements say. But why do all the diets talk about saturated fats?

Word bank



Carbon backbone: Carbon (C) skeleton

Esters: Fats or lipids

Fatty acid: Fatty acids are organic acids, particularly those consisting of unbranched chains of carbon

Lipid: A lipid is a hydrophobic, organic biomolecule that has energy storage and structural roles in cells

Mammalian: Warm-blooded animals that suckle their young, for example humans

Precursor: Person (or thing) coming before as a sign of what is to follow.

What I still need to know



Fatty acids

Fats are also biological macromolecules. A fat is made up of an alcohol called glycerol attached to three fatty acids, as shown in Figure 1.60.

Each fatty acid is made up of a carboxylic acid attached to a long hydrocarbon chain, as shown in Figure 1.61.

Fatty acids consist of two parts:

- a carboxylic acid group which is hydrophilic (attracted to water)
- a hydrocarbon chain which is hydrophobic (repelled by water), but is attracted to grease and oils.

Let's imagine that we have added soap to water in order to clean a dirty T-shirt:

- The hydrocarbon chain will attach itself to the soil particles in the dirty T-shirt, while the carboxylic acid will be attracted to the water.

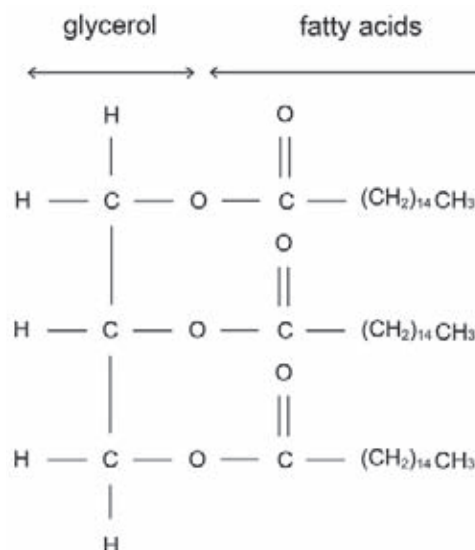


Figure 1.60: The structure of a fat – composed of an alcohol and three fatty acids

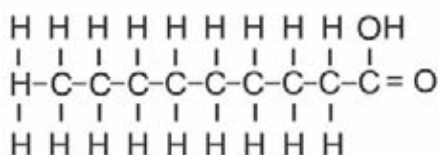


Figure 1.61: Example of a fatty acid

- In this way, the soil is pulled free of the T-shirt and is suspended in the water.
- In a washing machine or with vigorous hand-washing, this suspension can be rinsed with clean water.

Oil has the same structure as a fat, but is a liquid rather than a solid. Oils are found in plants, for example olive oil and sunflower oil, and fats are found in animals.

Soaps can be made from either fats or oils. Beef fat is a common source of fat, and vegetable oils such as palm oil are also commonly used. To make soap, sodium hydroxide (NaOH) or potassium hydroxide (KOH) must be added to a fat or oil. During this reaction, the glycerol is separated from the fatty acid in the fat and is replaced by either potassium or sodium ions. Soaps are the water-soluble sodium or potassium salts of fatty acids.

The chemical structure of a simple fatty acid

Fatty acids consist of a long carbon chain (also called an acyl chain) with a carboxylic acid at one end. The vast majority of fatty acids are un-branched linear molecules.

Substances which contain the carboxyl group, $-\text{COOH}$, make up the group of compounds known as the fatty acids or carboxylic acids. The general formula is shown in Figure 1.62, where R stands for hydrogen or any alkyl group. $\text{R}-\text{COOH}$

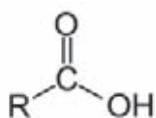


Figure 1.62: General formula for fatty acids

Name and chemical structure	Structural formula	Condensed formula
Methanoic acid (known as formic acid) H.COOH	$ \begin{array}{c} \text{O} \\ \\ \text{H}-\text{C}-\text{OH} \end{array} $	$ \begin{array}{c} \text{O} \\ \\ \text{HC}-\text{OH} \\ \text{or HCOOH} \end{array} $
Ethanoic acid (known as acetic acid) $\text{CH}_3.\text{COOH}$	$ \begin{array}{c} \text{H} & \text{O} \\ & \\ \text{H}-\text{C}-\text{C}-\text{OH} \\ \\ \text{H} \end{array} $	$ \begin{array}{c} \text{O} \\ \\ \text{CH}_3\text{C}-\text{OH} \\ \text{or CH}_3\text{COOH} \end{array} $



Name and chemical structure	Structural formula	Condensed formula
Propanoic acid (known as propionic acid) C_2H_5COOH	$ \begin{array}{c} H & H & O \\ & & \\ H-C & -C & -C-OH \\ & & \\ H & H & \end{array} $	$ \begin{array}{c} O \\ \\ CH_3CH_2C-OH \\ \text{or } CH_3CH_2COOH \end{array} $
Butanoic acid (known as butyric acid) C_3H_7COOH	$ \begin{array}{c} H & H & H & O \\ & & & \\ H-C & -C & -C & -C-OH \\ & & & \\ H & H & H & \end{array} $	$ \begin{array}{c} O \\ \\ CH_3(CH_2)_2C-OH \\ \text{or } CH_3(CH_2)_2COOH \end{array} $

Figure 1.63: Chemical structure and structural formulae of fatty acids

From Figure 1.63 it is also clear that all the structural formulae of the fatty acids follow the same pattern as for alkanes and alcohols.

Saturated and unsaturated fatty acids

Figure 1.64 shows three different types of fatty acids.

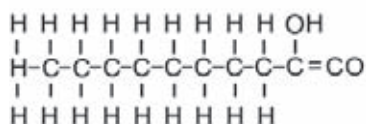


Figure 1.64a: Saturated fatty acid

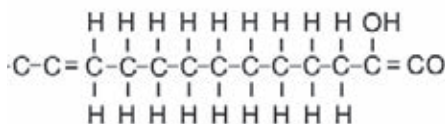


Figure 1.64b: Unsaturated fatty acid

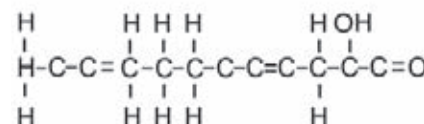


Figure 1.64c: Poly-unsaturated fatty acids

Saturated fatty acids contain all the hydrogen atoms possible. In these acids, the carbon backbone is composed of carbon-to-carbon single bonds, and is expressed as: $-C-C-C-C-$.

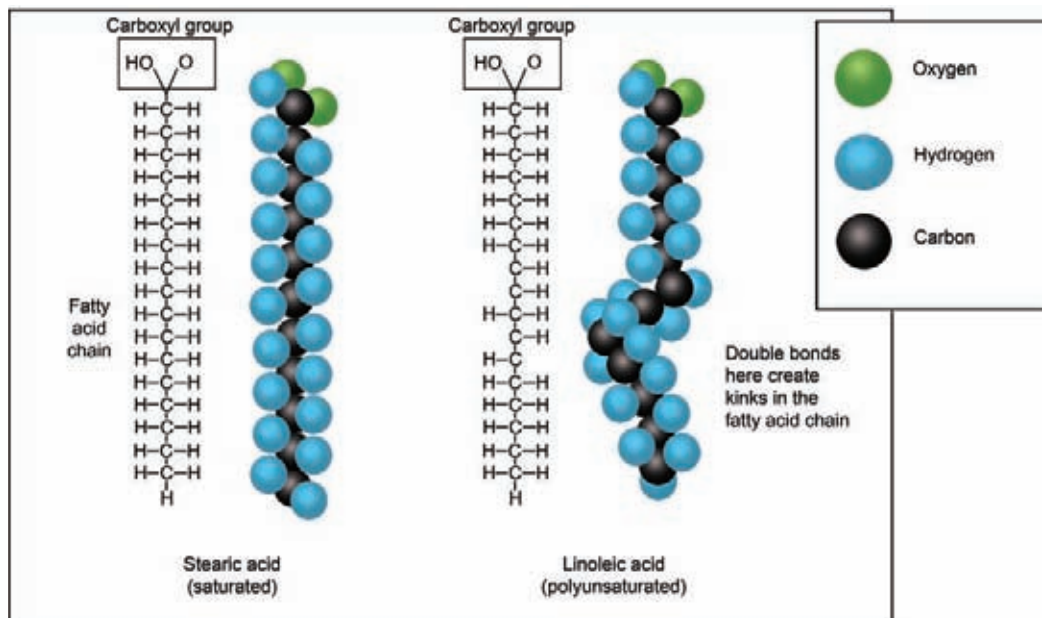
Unsaturated fatty acids have double bonds between one or more pairs of carbon in the chain, and is expressed as: $-C-C=C-C-C=C-C-$. Therefore the unsaturated fatty acids have less hydrogen.

If such an unsaturated fatty acid has more than one carbon-to-carbon double bond it is a **poly-unsaturated fatty acid**. Such fatty acids include cottonseed oil (linoleic acid) and linseed oil (linolenic acid). The presence of a double bond produces a rigid point in the fatty acid chain.

Unsaturated fatty acids (plant origin) are essential for good nutrition. They are precursors to important molecules in the human body, for example cell membranes are rich in unsaturated fatty acids. Chemical processes in humans (and other mammals) cannot produce double bonds in the fatty acid chain. It is therefore necessary to include a small amount of unsaturated fats in the diet. That is why linoleic and linolenic fatty acids are known as **essential fatty acids**.

Figure 1.65 shows the structures of saturated and unsaturated fatty acids.

Figure 1.65: Saturated and unsaturated fatty acids



Stearic acid is a fatty acid of animal origin; its carbon chain contains the maximum number of hydrogen atoms. Linoleic acid, abundant in cotton seeds, is an unsaturated fatty acid. Note the links where the double bonds occur in the polyunsaturated fatty acids.

Importance of saturated and unsaturated fatty acids

Saturated and unsaturated fatty acids carry out a number of important functions in the animal body. These include the following:

- Fatty deposits form below the skin of an animal and around important body organs. These deposits act as an insulator i.e. protect the body from getting too cold during cold weather, and help to keep the internal body heat fairly constant.
- Fatty acids stored in the body provide an energy source for animals – particularly during periods of low food supply.
- Fatty acids are essential for the formation of cell membranes. Cell membranes are made up of fatty acids and protein.
- Fatty acids produce water as a by-product when hydrolysed. This water helps to hydrate the body during periods of drought.
- The intake of too many saturated fatty acids can cause coronary and cardiac diseases, as in the case of human beings.

Comparing the melting points of saturated and unsaturated fatty acids:

Saturated acid	Formula	Melting point
Butyric acid	$C_4H_8O_2$	Liquid at room temperature (about $18^\circ C$)
Palmitic acid	$C_{16}H_{32}O_2$	$63^\circ C$
Stearic acid	$C_{18}H_{36}O_2$	$70^\circ C$



Unsaturated acid	Formula	Melting point
Palmitaleic acid	C16H30O2	Liquid at room temperature (about 18°C)
Oleic acid	C18H34O2	Liquid at room temperature (about 18°C)
Linoleic acid	C18H32O2	Liquid at room temperature (about 18°C)

- These differences in melting points are very important in physiology because they influence the properties of the fats and the way they react with other molecules in the body.
- Unsaturated acids can exist in different isomeric forms.

The differences between fatty acids and alcohols

The molecular structure of fatty acids is closely related to that of alcohols except that two hydrogen atoms, as indicated in the structural formula for an alcohol, are replaced by an oxygen atom. This is shown in Figure 1.66.

Alcohols	Methanol	Ethanol	Propanol	Butanol
	$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{OH} \\ \\ \text{H} \end{array}$ CH_3OH	$\begin{array}{c} \text{H} \text{ H} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{OH} \\ \quad \\ \text{H} \text{ H} \end{array}$ $\text{C}_2\text{H}_5\text{OH}$	$\begin{array}{c} \text{H} \text{ H} \text{ H} \\ \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{OH} \\ \quad \quad \\ \text{H} \text{ H} \text{ H} \end{array}$ $\text{C}_3\text{H}_7\text{OH}$	$\begin{array}{c} \text{H} \text{ H} \text{ H} \text{ H} \\ \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{O}-\text{H} \\ \quad \quad \quad \\ \text{H} \text{ H} \text{ H} \text{ H} \end{array}$ $\text{C}_4\text{H}_9\text{OH}$
Fatty Acids	Methanoic acid	Ethanoic acid	Propanoic acid	Butanoic acid
	$\begin{array}{c} \text{O} \\ \\ \text{H}-\text{C}-\text{OH} \end{array}$ HCO_2H	$\begin{array}{c} \text{H} \quad \text{O} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{O}-\text{H} \\ \\ \text{H} \end{array}$ $\text{CH}_3\text{CO}_2\text{H}$	$\begin{array}{c} \text{H} \text{ H} \quad \text{O} \\ \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{O}-\text{H} \\ \quad \\ \text{H} \text{ H} \end{array}$ $\text{CH}_3\text{CH}_2\text{COOH}$	$\begin{array}{c} \text{H} \text{ H} \text{ H} \quad \text{O} \\ \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{O}-\text{H} \\ \quad \quad \\ \text{H} \text{ H} \text{ H} \end{array}$ $\text{CH}_3\text{CH}_2\text{CH}_2-\text{COOH}$

Figure 1.66: Comparison of alcohols and fatty acids

You can see from the structural formulae in Figure 1.66 where the two hydrogen atoms (alcohol) are replaced by an oxygen atom (fatty acid), thus forming a double covalent bond.

All other fatty acids follow the same structural formula as the four examples shown in Figure 1.66.

Bio-molecules (lipids)

A simple lipid or fat can be understood if we look at the synthesis of the saturated fat, glycerylbuterate. This occurs when glycerol (alcohol) reacts with butanoic acid (fatty acid), as shown in Figure 1.67.

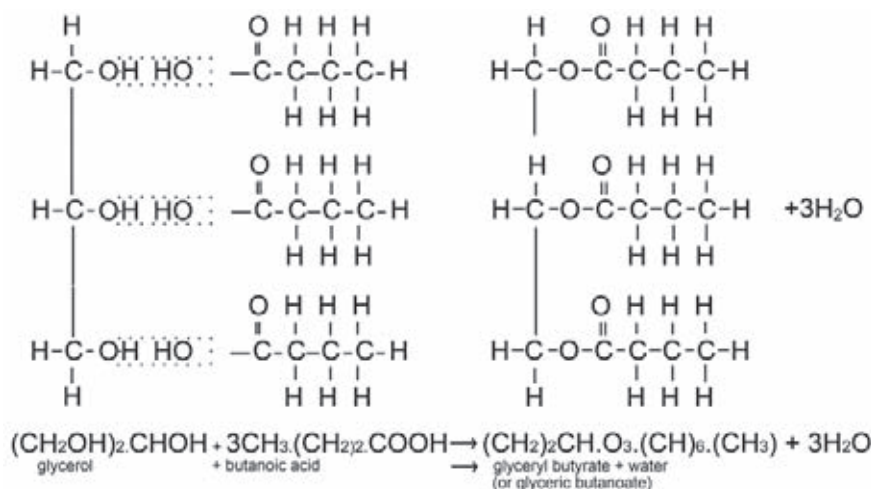


Figure 1.67: Chemical reaction between glycerol and butanoic acid

Note that the structural formula of butanoic acid is written in its mirror image.

Another example is the reaction between glycerol and stearic acid to form the fat, glyceric tristearate, as shown in Figure 1.68.

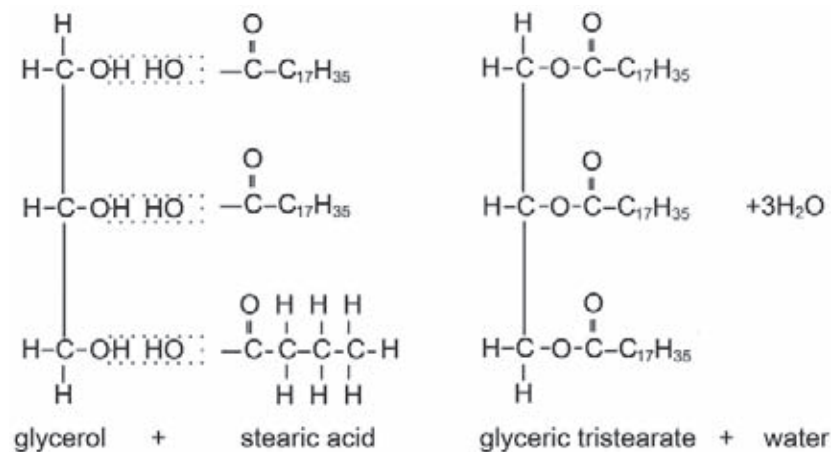


Figure 1.68: Chemical reaction between glycerol and stearic acid

The differences between fats and oils, saturated and unsaturated fats

When alcohols combine with a fatty acid, an ester is formed. These esters are also known as glycerides or fats.

The main difference between plant and animal fats is that plant fats generally have a much lower melting point than animal fats. Most plant fats have a melting point below 20°C. This is because these oils contain a large percentage of unsaturated fatty acids. The presence of the unsaturation in the acid component tends to lower the melting point, with the result that plant fats are liquid (oil).

The most common animal fats are lard and butter. Lard is prepared from pig fat, while butter is a dairy product. These fats contain mostly saturated fatty acids, such as palmitic and stearic acids, which have high melting points. These fats are in a solid form (fat).

Fats and oils are exactly the same, the only difference being that at normal (everyday) temperatures oils are liquid and fats solid.

In earlier days the use of butter, an animal fat, became unpopular because of its high melting point. It was difficult to spread butter on a slice of bread, especially on cold days. This situation resulted in the demand for a more user-friendly bread spread. During the 1960s scientists succeeded in turning plant fats into a more pliable medium to use with bread. The result was a yellow product, called margarine.

Margarine is made by hardening of oils. When it is churned with skim milk and artificially coloured, and with the addition of vitamin A, it has the flavour and appearance of butter, with added nutritional advantages.

The hardening of oils is done by a process called the hydrogenation of unsaturated fats. This method was developed to change plant oils into a more acceptable and usable hardened form. This discovery has changed the consumption of animal fats (butter), once a staple part of many people's diet, to the use of hardened plant fats (margarine) instead.

In hydrogenation the double bond between two carbon atoms in the unsaturated fatty acid part of a fat or oil is broken by the action of hydrogen and a catalyst. The double bond is broken and two hydrogen atoms are now added to the molecule, as you can see in Figure 1.69.

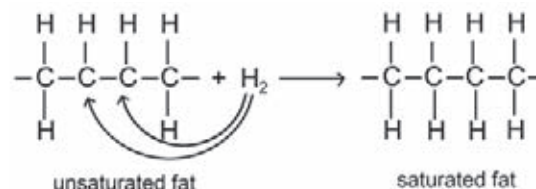


Figure 1.69: Unsaturated fat versus saturated fat

The main functions of lipids/fats in living organisms

Lipids (fats) are, in addition to carbohydrates, the main source of energy for all living organisms. Fats yield more energy on combustion than carbohydrates. However, the main function of fat is storage. Like starch and glycogen, fat is compact and insoluble and provides a convenient form in which energy-yielding molecules (fatty acids) can be stored until needed by the organism. Excess carbohydrates in the animal's body can be converted into fat. The fat deposits beneath the animal's skin and elsewhere represent potential sources of energy which can be used when needed.

Fats are also involved in the composition of certain structures in cells. An example is the plasma membrane, where the fat is combined with phosphoric acid to form phospholipids. In the formation of phospholipids the phosphoric acid reacts with one of the three hydroxyl groups of glycerol to form glycerol phosphoric acid. The glycerol's other two hydroxyl groups react with fatty acid chains in the usual way. This causes the lipid molecule to be polar. The glycerol phosphoric acids form the polar end and are therefore water soluble. The fatty-acid hydrocarbon chains are non-polar and thus water-insoluble. These properties of the phospholipid molecule are important in the formation and functioning of the plasma membrane, as Figure 1.70 shows.

Two of the carbon atoms of the glycerol attach to fatty acid chains. The other carbon atom is attached to phosphoric acid.

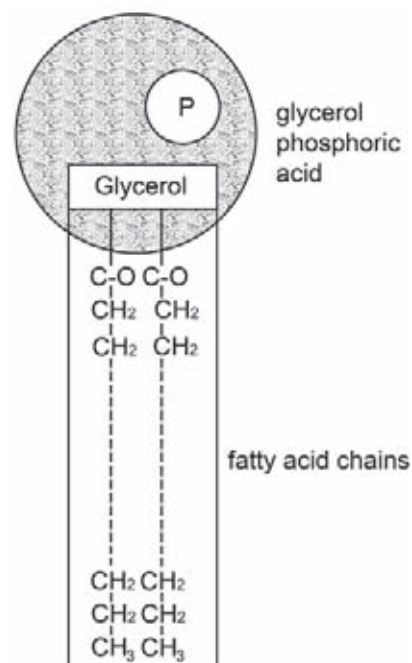


Figure 1.70: Structure of phospholipid

Lipids are also important in the skin of mammals. The dermis contains large deposits of sub-cutaneous fat which is mainly for storage, and also prevents excessive heat losses. It is extremely extensive in animals such as polar bears which live in cold climates. Lipids are also a constituent of the waxy cuticle of plants and insects. The water repelling properties of the lipid make the cuticle water-proof.

A fat layer around organs serves as a shock-absorber. For example, the kidneys are protected in this way.

Classroom activity 5

- 1 Name the following fatty acids and draw their structural formula:

a) H.COOH	b) $\text{CH}_3.\text{COOH}$
c) $\text{C}_2.\text{H}_5.\text{COOH}$	d) $\text{C}_3.\text{H}_7.\text{COOH}$
- 2 Name the four saturated fatty acids that you have learnt about in this unit.
- 3 Name the three unsaturated fatty acids that you have learnt about in this unit.
- 4 Give reason(s) why unsaturated fatty acids should be included in your daily diet.

Homework activity 5

- 1 Discuss the history of margarine as a household fat.
- 2 Write a paragraph on the importance of fats in the mammalian body.
- 3 Draw the structure of a phospholipid molecule, and explain its role in the body.

Extra practice 5

- 1 Identify activities of human beings which will demand a source of body energy.
- 2 Identify climatic conditions which will necessitate the intake of fat-rich food by humans.
- 3 When will animals – like beef cattle – become fat?
- 4 Under which climatic circumstances should animals be fed a ration rich in lipids?



Summary

In this unit we learnt about:

- Fatty acids:
 - the chemical structure of a simple fatty acid
 - the difference between saturated and unsaturated fatty acids (their structures and importance)
 - the differences between fatty acids and alcohols based on their structural formulae
- Bio-molecules (lipids):
 - basic composition of a simple lipid/fat
 - the differences between fats and oils, and saturated and unsaturated fats
 - the importance of lipids/fats in living organisms.

Unit 6: Proteins

What will you learn about in this unit?

- The structure of the monomers of proteins (amino-acids)
- The differences between simple and complex proteins (also referred to as essential amino-acids and non-essential amino-acids)
- The structural and chemical formulae of polypeptides/simple proteins
- The synthesis and hydrolysis of proteins
- The main functions and importance of proteins in living organisms.

Let's talk about this unit

Proteins are a very important part of any cell, and they perform many functions such as support, storage and transport within the body. Your hair and nails are made of protein, your body defends itself with antibodies (which are proteins), and proteins in your eyes enable you to see.

Together with carbohydrates, proteins are very important in our everyday lives. Proteins consist mostly of the elements carbon (C), hydrogen (H), oxygen (O) and nitrogen (N). Many proteins also contain the elements of sulphur (S) and phosphorus (P).

What do I know already?



In Grade 10 you learnt about proteins, and that proteins are used as antibodies in animal bodies. You also learnt that all the enzymes secreted in the alimentary canal are proteins.



- Name the elements in proteins.
- What are the functions of proteins in the human body?

Word bank



Chemical reactions: Reactions caused by electron transfer

Complex proteins: Proteins in which simple proteins are combined with a non-protein radical, such as nucleoproteins, glycoproteins and hemoglobine

Conjugation: These reactions involve covalent attachment of small polar endogenous molecules such as glucuronic acid, sulphate or glycine to form water-soluble compounds

Connective tissue: Tissue which keeps body organs in place

Essential amino-acids (EAAs): Amino-acids that humans and other animals must ingest because the body requires them for good health but cannot synthesise them



Monomer: A molecule of any class of compounds, mostly organic, that can react with other molecules of the same or other compound to form very large molecules, or polymers

Non-essential amino-acid: An amino-acid that animals can synthesise for themselves

Peptides: Short polymers of amino-acid monomers linked by peptide bonds

Polymer: Any of a class of natural or synthetic substances composed of very large molecules (macromolecules) that are multiples of simpler chemical units called monomers. Polymers make up many of the materials in living organisms, including, proteins, cellulose and nucleic acids

Simple proteins: Those proteins which yield only amino-acids (or their derivatives on hydrolysis) such as albumins, globulins, glutelins and protomins

Trans-amination: Transfer of an amino group from one chemical compound to another.

What I still need to know



Structure of the monomers of proteins (amino-acids)

The monomers of proteins are called amino-acids. An amino-acid is an organic molecule that contains a carbon side chain, an amino group ($-\text{NH}_2$) and a carboxyl ($-\text{COOH}$) group that gives it acidic properties. Figure 1.71 shows this.

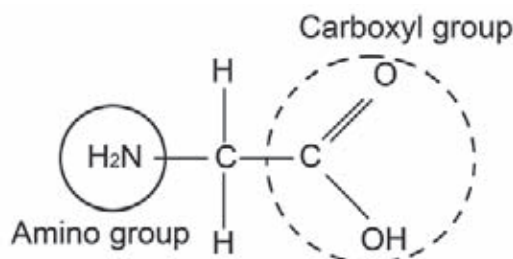


Figure 1.71: Carboxyl group in an amino-acid (glycine)

The carbon side chain varies from one amino-acid to the next, and is sometimes simply represented by the letter 'R' in a molecule's structural formula.

The structure of a simple amino-acid is illustrated in Figure 1.72.

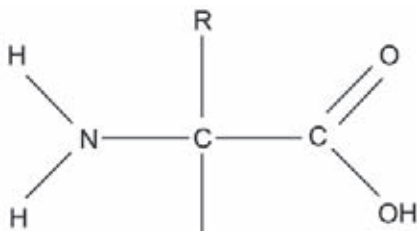


Figure 1.72: Structure of a simple amino-acid

R is the general formula for H or a carbon chain. The arrangement and the number of atoms of this group determine the different amino-acids.

Figure 1.73 shows the structures of a few simple amino-acids.

Glycine (Gly)	Alanine (Ala)	Cysteine (Cys) (Aminomercaptopropionic acid)
The R-group is an H-atom	The R-group is now CH₃	The R-group is CH₂SH which contains sulphur

Figure 1.73: Structures of a few simple amino-acids

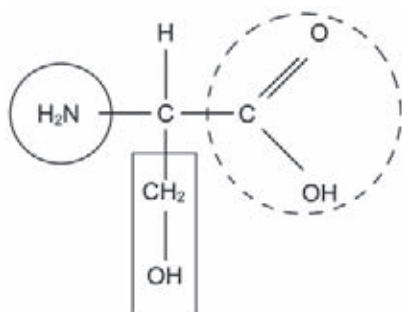


Figure 1.74: The 'R' group in serine is CH₂-OH

Although each of these amino-acids has the same basic structure, their side chains ('R' groups) are different. In the amino-acid glycine, the side chain only consists of a hydrogen atom, while alanine has a methyl side chain.

Amongst other things, the side chains affect whether the amino-acid is hydrophilic (attracted to water) or hydrophobic (repelled by water). If the side chain is polar, then the amino-acid is hydrophilic, but if the side chain is non-polar then the amino-acid is hydrophobic. Glycine and alanine both have non-polar side chains, while serine has a polar side chain, as you can see in Figure 1.74.

The differences between simple and complex proteins

The various proteins cannot be identified from each other by simple chemical methods. Their classification is therefore based mainly on physical properties.

Simple proteins

This group includes those proteins which yield only amino-acids (or their derivatives on hydrolysis), such as albumins, globulins, glutelins and protomins. These subgroups - each of which contains many individual members - are differentiated according to their degrees of solubility. Some are soluble in water, others in salt solution and other in alcohol. For example, the albumins which include egg albumin are soluble in water. The legumin in beans and peas are insoluble in water.

Complex or conjugated proteins

These are the proteins in which simple proteins are combined with a non-protein radical. Five groups can be distinguished:

- Nucleoproteins: compounds of one or more protein molecules with nucleic acid. They are present in germs of seeds.



- Glycoproteins: compounds of the protein molecule, and a substance(s) containing a carbohydrate group other than a nucleic acid, for example mucin.
- Phosphoproteins: compounds of the protein molecule with a phosphate containing substance other than a nucleic acid, for example casein.
- Haemoglobine: compounds of the protein molecule with hematin, for example haemoglobin is the iron-containing protein attached to red blood cells that transports oxygen from the lungs to the rest of the body.
- Lecithoproteins: compounds of the protein molecule with lecithin, for example tissue fibrinogen.

The main proteins are summarised in the following table.

Name	Structure	Functions
Enzymes	Two or more polypeptides	Speeds chemical reactions in cells as a catalyst
Antibodies	Four polypeptides	Defends against invading organisms
Hormones	One or two folded polypeptides	Stimulates responses in target cells
Fibrous protein	Polypeptides held by hydrogen bonds in side-by-side array	Structural protein in hair (keratin) in tendons (collagen)
Conjugated protein	Polypeptides plus non-protein side groups (sugars or lipids)	Important in defence and communication

The structural and chemical formulae of polypeptides/simple proteins

Polypeptide bonds are formed by joining together two amino-acids with the loss of a water molecule (known as condensation). Figure 1.75 shows an example of a simple peptide bond.

The product of a peptide bond is known as a dipeptide. (This is when two peptides are joined together.)

Polypeptides can vary in length from a few amino-acids to a thousand or more. The polypeptide chains are then joined to each other in different ways to form a protein. It is the sequence of the amino-acids in the polymer that gives a protein its particular properties.

Figure 1.76 shows another example of a polypeptide, namely dipeptide $\text{NH}_2\text{-Gly-Gly-COOH}$.

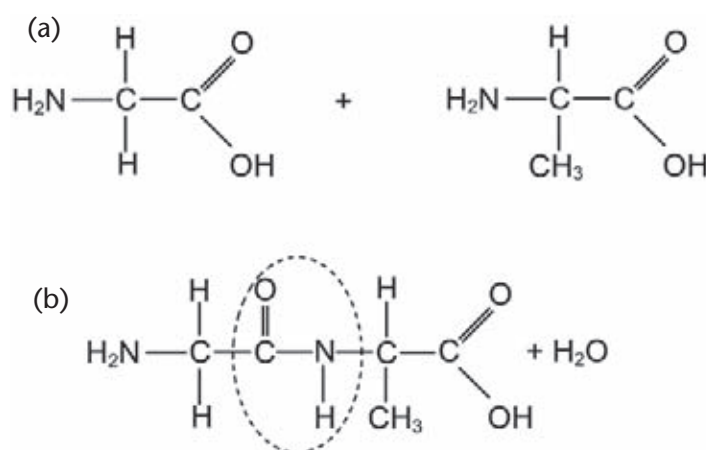


Figure 1.75: (a) Two amino-acids (glycine and alanine) combine to form part of a polypeptide chain. (b) The amino-acids are joined by a peptide bond between a carbon atom of one amino-acid and a nitrogen atom of the other amino-acid.

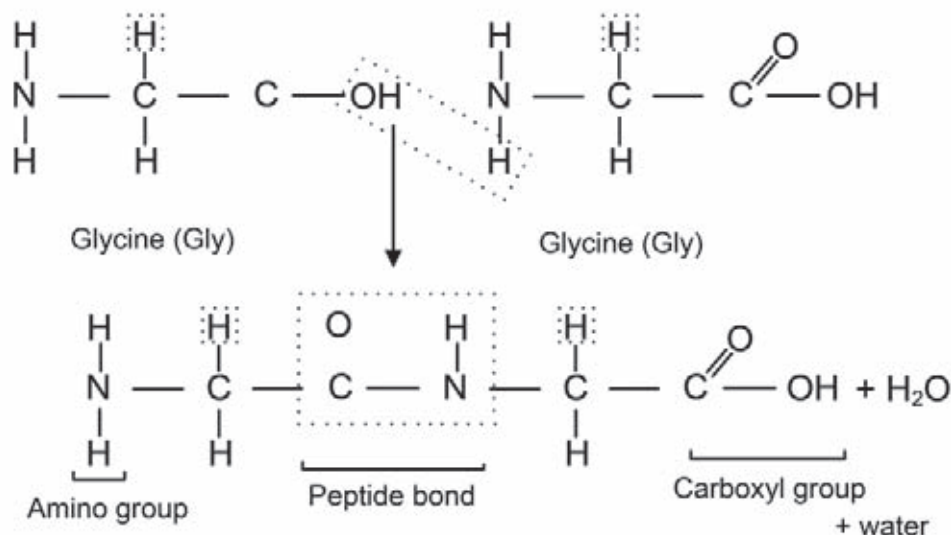


Figure 1.76: Example of a polypeptide: dipeptide $\text{NH}_2\text{-Gly-Gly-COOH}$

Polypeptide chains are often linked to one another. This can happen in many different ways. The most important R-group involved in cross-linking is that of cystine (Cys), which contains the SH-group. In nature this happens, for example, in a wool molecule. The long polypeptide chains lie more or less parallel lengthwise.

The sequence of the amino-acids in the chain is known as the protein's **primary structure**. As the chain grows in size, it begins to twist, curl and fold upon itself. The different parts of the polypeptide are held together by hydrogen bonds, which form between hydrogen atoms in one part of the chain and oxygen or nitrogen atoms in another part of the chain. This is known as the **secondary structure** of the protein. Sometimes, in this coiled helical structure, bonds may form between the side chains (R groups) of the amino-acids. This results in even more irregular contortions of the protein. This is called the **tertiary structure** of the protein.

The synthesis and hydrolysis of proteins

When peptides join to form peptide chains water is given off in condensation. This leads to the formation of proteins. **Hydrolysis** is the opposite process where water is added and whereby simple proteins are broken down to shorter peptide chains and eventually to amino-acids.

Synthesis of proteins

The synthesis of simple proteins (consisting only of amino-acids) occurs through repeated condensation reactions. Through these reactions dipeptides, tripeptides, peptones and polypeptides are formed. Water is the by-product.

As you have learnt, proteins are long chains of amino-acids. There are thousands of different proteins which contribute to the functioning of organisms and the structure of their fibre and organs. There are a total of twenty amino-acids which are used in the synthesis of these different proteins.



The type of protein that is synthesised in the body cell depends on three things:

- The number of amino-acids in the protein chain. This number can vary from as few as 30 amino-acids (small molecule) to more than 50 000 amino-acids (giant protein molecules). On average protein molecules consist of 500 amino-acids.
- The type of amino-acids in the protein molecule.
- The order in which amino-acids are arranged in the chain.

One can compare the 26 letters of the alphabet with the 20 natural amino-acids. Just as millions of different words are possible from different arrangements of the letters, so too many kinds of proteins can be synthesised from the different arrangements of the amino-acids.

The arrangement of the amino acids in the protein molecule (in a chain formation) is directed by the nucleic acids. The nucleic acids are unique substances of which there are two kinds – deoxyribonucleic acid (DNA) and ribonucleic acid (RNA).

Each protein is different because of its unique sequence of amino-acids. A **gene** controls how the amino-acids arrange themselves to form the specific proteins that are needed by an organism.

The DNA polymer is made up of monomers called nucleotides. Each nucleotide has three parts: a sugar, a phosphate and a nitrogenous base. DNA is a double-stranded helix (a helix is basically a coil). Or, you can think of it as two RNA molecules bonded together, as shown in Figure 1.77.

From Figure 1.77, we can see that DNA is made of four types of nucleotides, which are linked covalently into a polynucleotide chain (a DNA strand) with a sugar-phosphate backbone from which the bases (A, C, G, and T) extend. A DNA molecule is composed of two DNA strands held together by hydrogen bonds between the paired bases. The arrowheads at the ends of the DNA strands indicate the polarities of the two strands, which run anti-parallel to each other in the DNA molecule. In Figure 1.77, at the bottom left, you can see that the DNA molecule is shown straightened out, but in reality, it is twisted into a double helix, as shown on the right.

If a cell needs to manufacture a certain protein, such as haemoglobin, the correct number and types of amino-acids must be arranged in the correct sequence in the proteins chain (of amino acids).

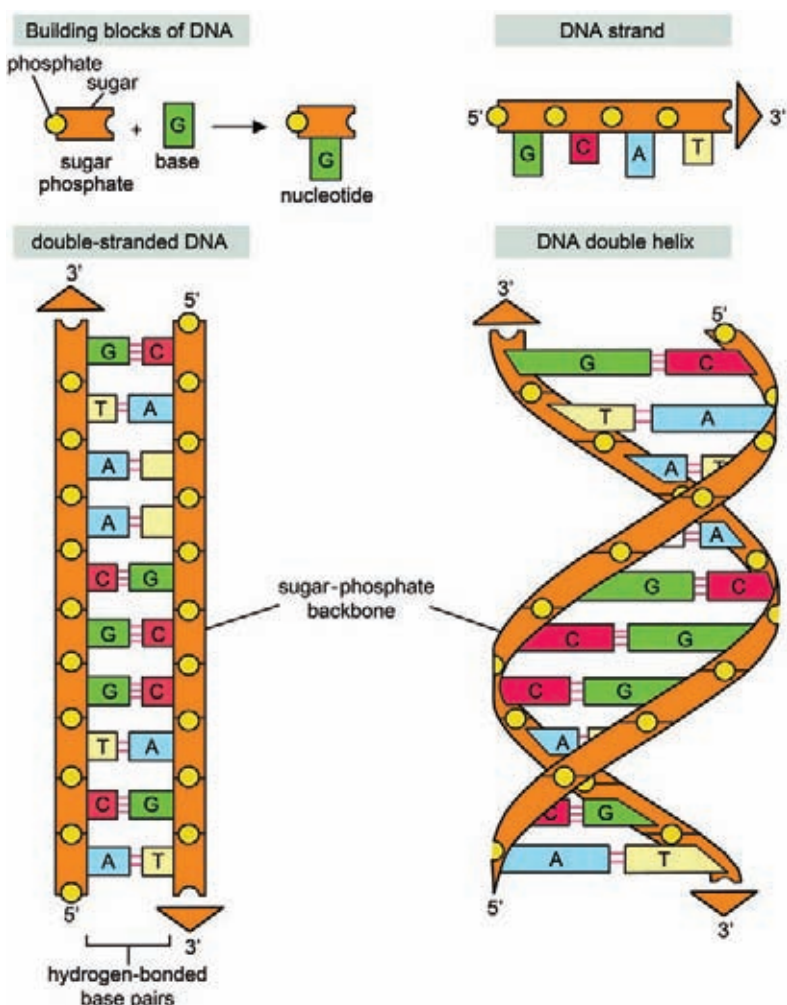


Figure 1.77: DNA and its building blocks

The messenger RNA now enters the cytoplasm and the ribosomes 'read' the message that is delivered by the RNA (from the DNA). In the ribosome the haemoglobin protein molecule is synthesised according to the code as received from the DNA through the messenger RNA.

Note: it is the DNA of an organism that determines the order in which amino-acids combine to make a protein.

Hydrolysis of proteins

Hydrolysis is the opposite process of the condensation reactions. It is the reaction whereby simple proteins are gradually broken down by the addition of water. The long polypeptide chains are broken down into shorter polypeptide chains. These shorter polypeptide chains are broken down into peptides and amino-acids. Eventually all peptides are broken up into amino acids. This process is controlled by enzymes.

When a complex polypeptide chain has become shorter during the hydrolysis of a protein, it becomes soluble in water. This shortened polypeptide is now known as a peptone. The peptones are a very important group of proteins. They consist of a polypeptide chain and a non-protein part. The latter can contain various elements such as phosphorus, iron and sulphur. An example is the protein casein, found in milk.

The main functions and importance of proteins in living organisms

Proteins have a number of functions in living organisms:

- **Structural proteins** such as collagen in animal connective tissue and keratin in hair, horns and feather quills, all provide support. Collagen is the principal protein of connective tissues such as tendons. Keratin is the principal component of hair. Each hair consists of cells that die after becoming packed with this tough protein. Keratin is organised very much like a steel cable with several levels of twisted strands, as shown in Figure 1.78.
- **Storage proteins** such as albumin in egg white provide a source of energy. Plants store proteins in their seeds to provide energy for the new growing plant.
- **Transport proteins** transport other substances in the body. For example, haemoglobin in the blood is a protein that contains iron. Haemoglobin has an affinity (attraction) for oxygen and this is how oxygen is transported around the body in the blood.
- **Hormonal proteins** coordinate the body's activities. For example, insulin is a hormonal protein that controls the sugar levels in the blood.
- **Enzymes** are chemical catalysts and speed up chemical reactions. Digestive enzymes such as amylase in saliva help to break down polymers in food. Enzymes play an important role in all cellular reactions such as respiration and photosynthesis.

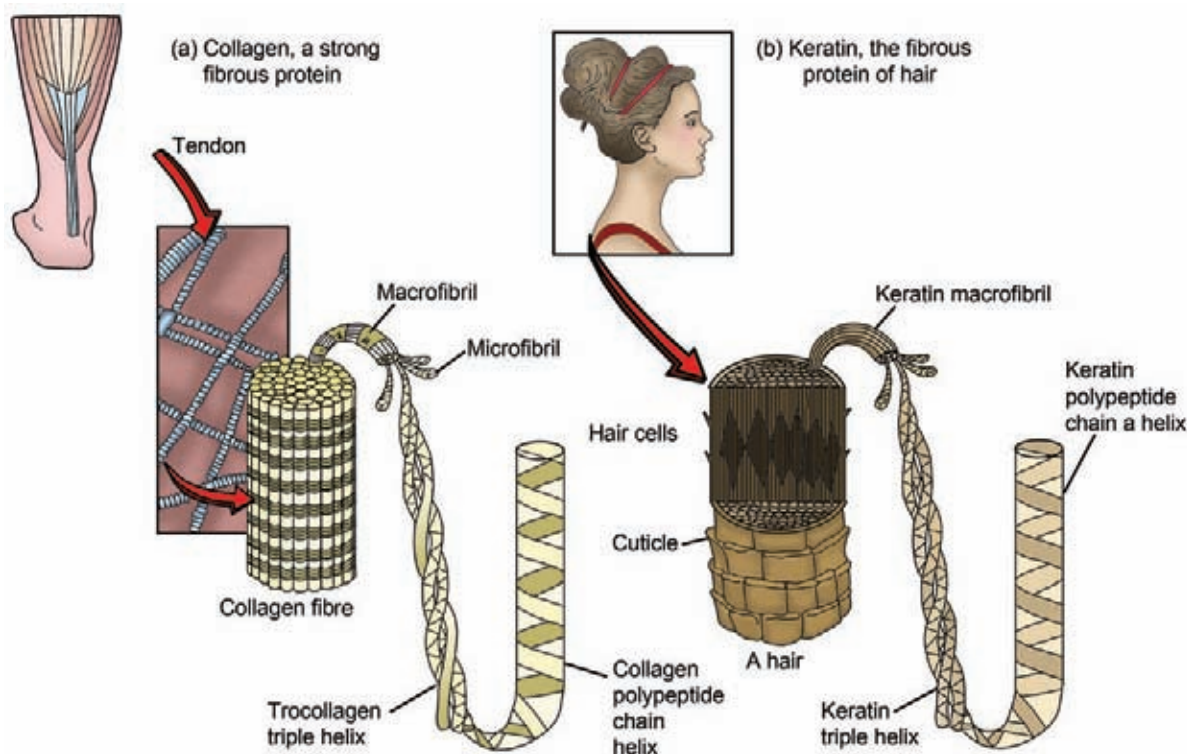


Figure 1.78: Keratin

Essential and non-essential amino-acids

Plants and a large number of micro-organisms can synthesise proteins from simple nitrogen compounds such as nitrates. The amino group cannot be synthesised by animals. Certain amino-acids can be produced through another process known as trans-amination, but another group of amino-acids cannot be effectively synthesised in the animal body. The former are known as non-essential amino-acids (because the animal can synthesise these for itself) while the latter are known as essential amino-acids (because the animal cannot produce them for itself).

The essential amino-acids must be present in the feeds of all animals except ruminants. Without these essential amino-acids, the animals cannot synthesise their own proteins and will therefore suffer from malnutrition. In the case of ruminants, the essential amino-acids can be synthesised with the acid of rumen microbes.

Classroom activity 6

- 1 What is the main function of the following groups in an amino-acid:
 - a) The amino-group
 - b) The carboxyl group?
- 2 Describe the structure of a basic monomer of protein (also known as an amino-acid). Use diagrams to support your explanation.
- 3 Name any two examples of the group of simple proteins.

- 4 Name two examples of structural proteins.
- 5 Explain how 20 different amino-acids can be responsible for the formation of countless different kinds of proteins.
- 6 What determines the type of protein that is synthesised?

Homework activity 6

- 1 Explain how a polypeptide bond is formed. Use the amino-acids glycine and alanine to show how such a bond is formed. Draw the structural formulae to support your explanation.
- 2 Describe the process of protein synthesis involving the two nucleic acids named in the previous question.

Extra practice 6

- 1 Why can ruminants (e.g. cattle) go without the essential amino-acids?
- 2 Explain what happens when polypeptide chains are hydrolysed to form peptones and then amino-acids.

Summary

In this unit we have learnt about the:

- Structure of the monomers of proteins (amino-acids)
- Differences between simple and complex proteins (also referred to as essential amino-acids and non-essential amino-acids)
- Structural and chemical formulae of polypeptides/simple proteins
- Synthesis and hydrolysis of proteins
- Main functions/importance of proteins in living organisms.



Unit 7: Carbohydrates

What will you learn about in this unit?

- The basic chemical composition of carbohydrates
- The main classifications of carbohydrates – monosaccharides, disaccharides and polysaccharides (with relevant examples) and their structural formulae
- The general formulae of carbohydrates
- Structural and chemical formulae of simple sugars (monosaccharides)
- The main functions of carbohydrates in living organisms

Let's talk about this unit

Carbohydrates are biological macromolecules that are found in living organisms. Other biological macromolecules include molecules such as proteins and nucleic acids. A biological macromolecule is a polymer that occurs naturally in living organisms. These molecules are essential to the survival of life.

Carbohydrates include sugars and their polymers. A key characteristic of carbohydrates is that they contain only the elements carbon, hydrogen and oxygen.

Carbohydrates are commonly found in most organisms. They play important roles in organism structure, and are a primary energy source for animals and plants. Most carbohydrates are sugars or are composed mainly of sugars. By far the most common carbohydrate found in nature is glucose, which plays a major role in cellular respiration and photosynthesis. Some carbohydrates are for structural purposes, such as cellulose (which composes plant cell walls) and chitin (a major component of insect exoskeletons). However, the majority of carbohydrates are used for energy purposes, especially in animals.

What do I know already?



In Grade 10 you learnt about the different kinds of carbohydrates, namely the monosaccharids and the polysaccharides. You learnt that besides lipids, we need also carbohydrates for energy. The main energy-provider is the monosaccharide, glucose.

Check
myself

- Name the polysaccharide that is stored in the human liver.
- Name the monosaccharide that provides the main fuel for respiration.

Word bank



Aldo ring: Refers to the position of the oxygen atom in the carbohydrate; in the aldo ring the oxygen atom is between the first and the fifth carbon atoms

Disaccharides: Formed when two monosaccharide molecules join to form one molecule

Empirical formulae: Formulae which are reduced to their simplest terms

Keto ring: Refers to the position of the oxygen atom in the carbohydrate; in the keto ring the oxygen is between the second and fifth carbon atoms

Metabolism: Reactions (building up or breaking down) that occur in an organism

Monosaccharides: The simple sugars, which cannot be broken down into simpler organic compounds by adding water (hydrolysis)

Multiple: More than one (an increase in numbers)

Perennials: Plants that grow for more than one season

Polysaccharides: Formed when a large number of monosaccharides join together

Sturdiness: Strong and solid

What I still need to know



The basic chemical composition of carbohydrates

Carbohydrates contain only the elements carbon, hydrogen and oxygen. The name carbohydrate comes from a French word which means hydrate of carbon.

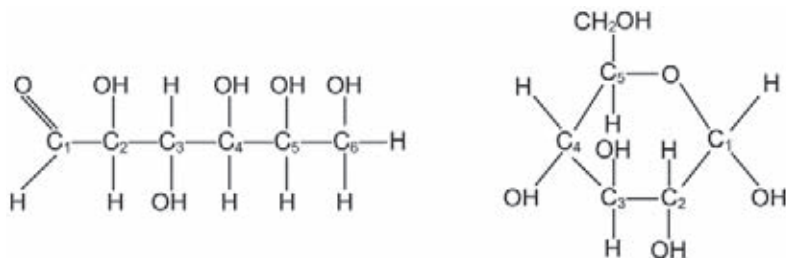


Figure 1.79: The open chain (a) and cyclic (b) structure of a glucose molecule

In the carbohydrate monomers, every carbon except one has a hydroxyl group attached to it, and the remaining carbon atom is double bonded to an oxygen atom to form a carbonyl group. One of the most important monomers in the carbohydrates is glucose. The glucose molecule can exist in an open-chain (acyclic) and ring (cyclic) form, as Figure 1.79 shows.

The main classifications of carbohydrates

All carbohydrates may be sub-divided into three main classes, namely monosaccharides, disaccharides and polysaccharides.

Monosaccharides

Monosaccharides are the simplest of all carbohydrates and cannot be divided into simpler compounds by adding water (hydrolysis). (Sacharum is the Latin word for sugar and mono means one.)

- They are usually sweet and very soluble in water.
- The monosaccharides, glucose and fructose are found in plants (seeds, roots and fruit juices).
- They are the only sugars which are found in a pure form in nature.



Monosaccharides include all the simple sugars. These sugars can be divided into than two groups:

- pentoses have five carbon atoms per molecule, for example ribose
- hexoses have six carbon atoms per molecule, for example glucose, galactose and fructose.

Glucose is the most common and important monosaccharide. It is intensely involved in energy metabolism. Glucose also forms the building blocks of most polysaccharides. Glucose is called blood sugar, corn sugar or grape sugar, depending on its source. In the medical world it is called dextrose. Other common monosaccharides are galactose and fructose.

Disaccharides

Disaccharides ('double sugar') are formed when two monosaccharide molecules join to form one molecule. In this way a double sugar is formed, and water is given off (condensation). Disaccharides can be broken down into simple sugars when water is added to them (hydrolysis). Disaccharides are formed as follows:
monosaccharide + monosaccharide + water

The most common disaccharides are shown in the table.

Name	Formed by
Lactose	(glucose + galactose + water)
Sucrose	(glucose + fructose + water)
Maltose	(glucose + glucose + water)

Disaccharides contain two monosaccharides. The most well-known disaccharide is sucrose. It is made up of one glucose and one fructose sub-unit. Sucrose has to undergo hydrolysis (adding of a water molecule) to split it into two monosaccharides. When this process takes place in an animal's alimentary canal, it is called digestion. When digested to glucose and fructose, the monosaccharides provide energy to the body. Another important disaccharide is lactose, which consists of the two monosaccharides, glucose and galactose. Since lactose is found only in milk, it is called 'milk sugar'. Lactose is not as sweet as sucrose, but babies thrive on it.

Polysaccharides

When a large number of monosaccharides join together, multiple sugars, or polysaccharides, are formed. When smaller molecules of polysaccharides join to form large molecules this is known as polymerisation. The large molecules are known as polymers of monosaccharides. The most important polysaccharides are starch, cellulose, glycogen and dextrin.

The polysaccharides are all examples of familiar carbohydrates:

- **Starch** is found in plants such as rice, wheat, maize and potatoes. It forms a very important part of our daily diet. Starch is used by plants to store excess glucose, and consists of long chains of glucose monomers. Potatoes are made up almost entirely of starch. This is why potatoes are such a good source of energy.

Animals are also able to store glucose, but as a compound called glycogen, rather than as starch.

- **Dextrose** is formed from starch and is a partly broken-down stage of food. This happens when starch is partly hydrolysed (water is added).
- **Glycogen** is usually found in the liver and muscles of animals, where it is stored as a concentrated carbohydrate.
- **Cellulose** is found in the cell walls of plants and is used by plants as a building material (gives sturdiness to plants). Cellulose is also made up of chains of glucose molecules, but the bonding between the polymers is slightly different from the bonding in starch.
- **Lignin** is also an important carbohydrate, but its structure is completely different from the others that we have discussed. Lignin forms the woody part in plants and is found mostly in older plants, such as perennials.

The general formulae of carbohydrates

The term 'carbohydrate' means hydrate of carbon. This is made clear by the empirical formula (CH_2O_n). Empirical formulae are those formulae which are reduced to their simplest terms. The 'n' in the empirical formula means that there can be any multiple of CH_2O .

To understand the general formulae of carbohydrates, you have to know the following:

- Due to some chemical properties of hexose the carbon atoms are not arranged in straight lines but form rings.
- The rings are formed because of the linking of two carbon atoms to each other by an oxygen atom.
- Because the oxygen atom may take either of two positions, two types of rings may be formed: aldo and keto rings, as Figure 1.80 shows.

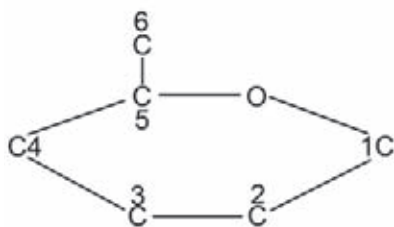


Figure 1.80a: Aldo ring

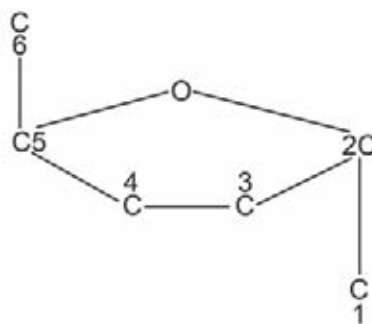


Figure 1.80b: Keto ring

The carbon atoms in these rings are numbered in a specific way:

- in the aldo ring the oxygen atom is between the first and the fifth carbon atoms.
- in the keto ring the oxygen is between the second and fifth carbon atoms.

The structural and chemical formulae of monosaccharides (simple sugars)

Figure 1.81 gives the chemical and structural formulae of three simple sugars.

Name and chemical formulae	Structural formula
Glucose $C_6H_{12}O_6$	Hexose ring
Galactose $C_6H_{12}O_6$	Aldo ring
Fructose $C_6H_{12}O_6$	Keto ring

Figure 1.81: Structural formulae of some simple sugars

The only difference between glucose and galactose is the position of the -OH group on the fourth carbon atom.

A monosaccharide consists of either a short chain or a ring of carbon atoms. This ring consists of five or six carbon atoms with nearly every carbon having a hydroxyl (-OH) and a hydrogen (-H) side group, as you can see in Figure 1.82.

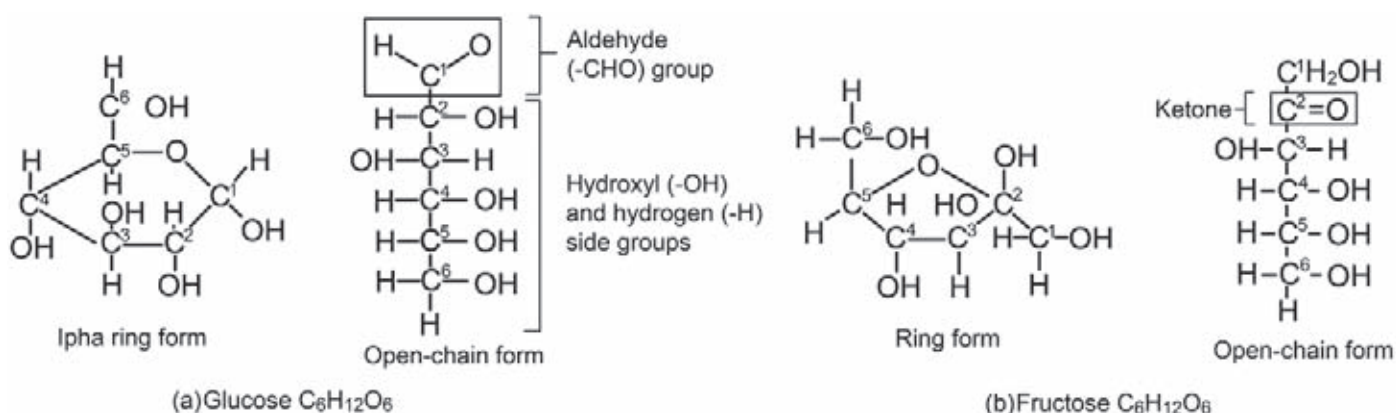


Figure 1.82: The monosaccharides glucose and fructose – ring and open-chain forms

When the monosaccharides are present in disaccharides or polysaccharides, they are always in their ring form.

The structural and chemical formulae of disaccharides

Figure 1.83 shows the structural formulae of the chemical combination of two glucose molecules to form maltose by condensation synthesis.

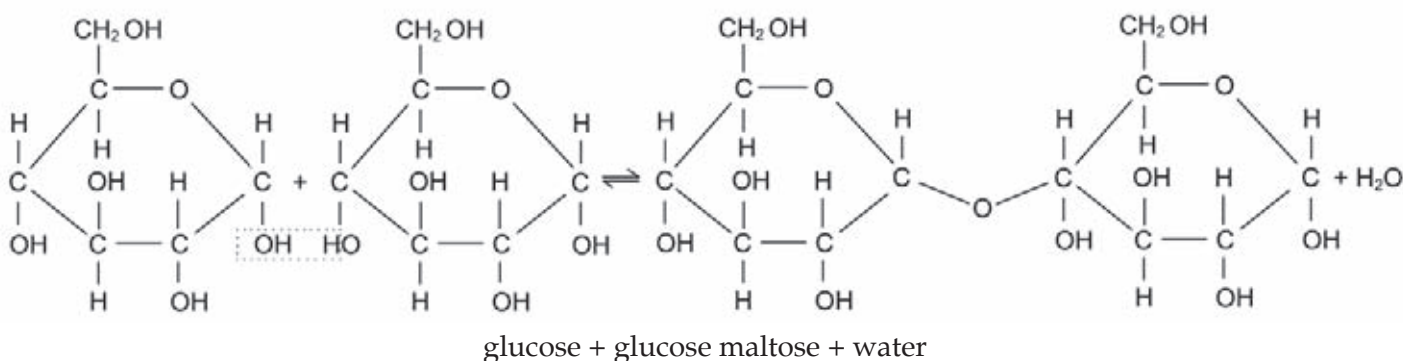


Figure 1.83: Chemical combination of two glucose molecules to form maltose by condensation synthesis

This chemical reaction is reversible. A disaccharide molecule is formed by the condensation of two monosaccharide molecules. The reverse is possible when the disaccharide molecule is split into two monosaccharide molecules through a process of hydrolysis.

The general formulae of a disaccharide can be demonstrated in the formation of maltose, as shown in Figure 1.84.

monosaccharide + monosaccharide disaccharide

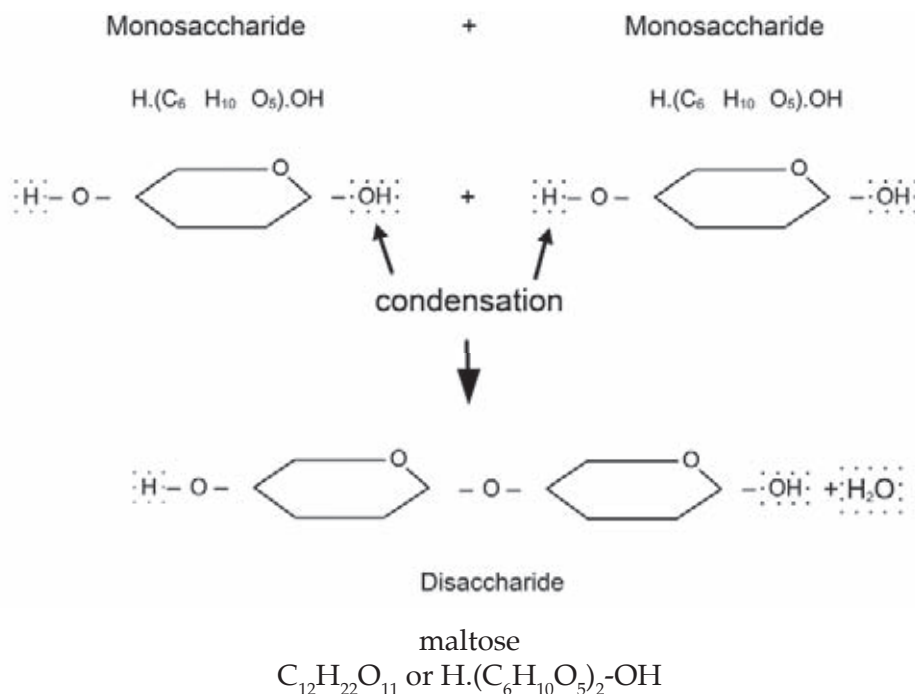


Figure 1.84: Formation of maltose

In the same way molecules of lactose are formed. Their structural formulae are given in Figure 1.85.

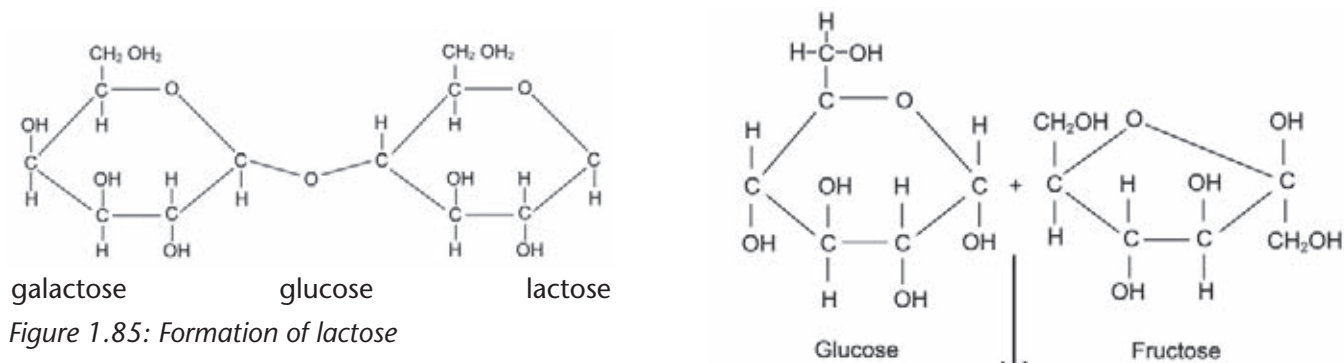


Figure 1.85: Formation of lactose

Disaccharides are the double sugars which contain two monosaccharides. Sucrose is a common disaccharide where the two six-carbon monosaccharides – glucose and fructose – are covalently bonded together through a dehydration reaction. During this reaction ($-OH$) side groups in adjacent monomers are brought together and a water molecule (H_2O) is removed, while an oxygen ($-O$) linkage is formed. This is shown in Figure 1.86.

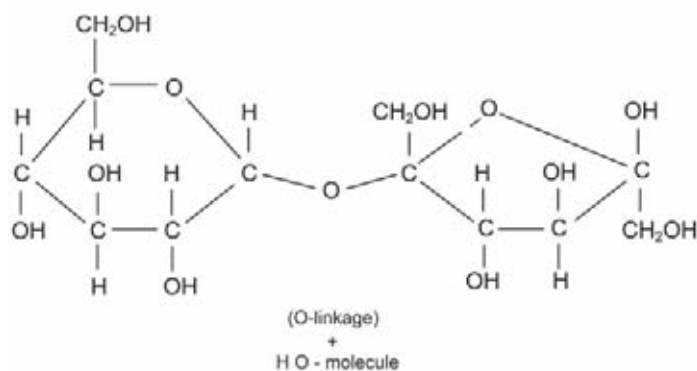


Figure 1.86: Dehydration reaction

The structural and chemical formulae of polysaccharides

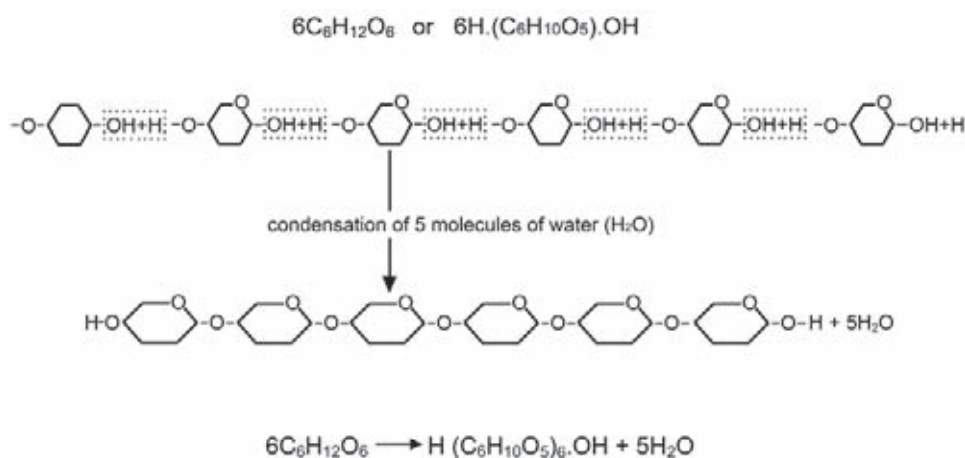


Figure 1.87: Chain model of hexose rings

Polysaccharides are formed in the same way and can be demonstrated by a chain model of hexose rings, as shown in Figure 1.87.

We have already seen how maltose is synthesised by condensation from two glucose molecules. The polysaccharides are synthesised in the same way by the condensation of a large number (poly = many) of glucose molecules (hexose rings). This is shown in Figure 1.88.

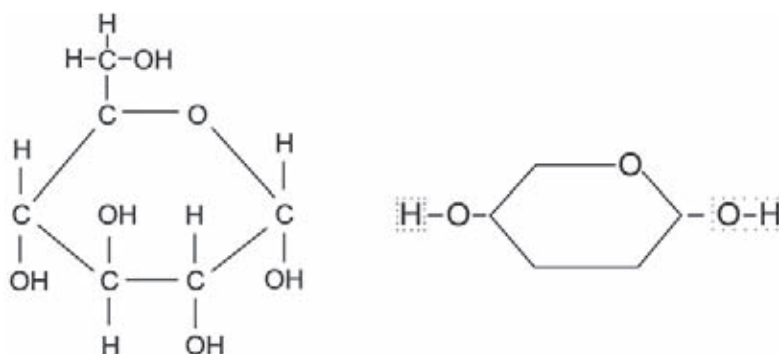


Figure 1.88: Maltose is synthesised by condensation

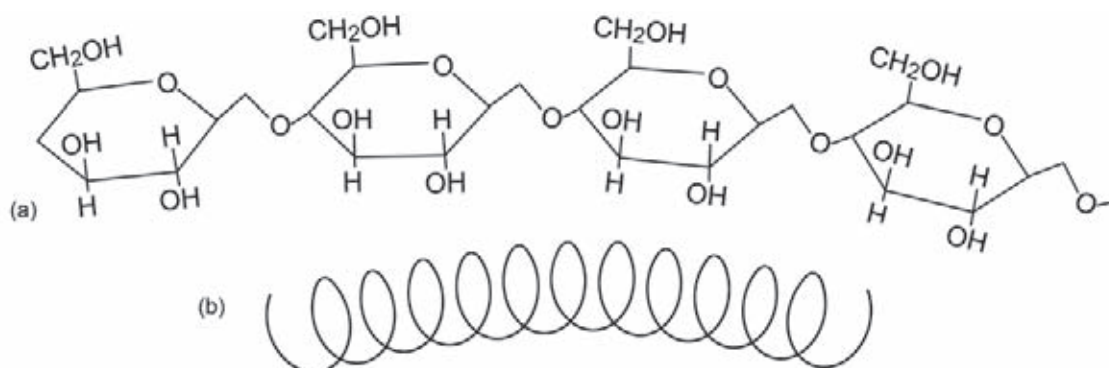
The general molecular formula for a polysaccharide is $(\text{C}_6\text{H}_{10}\text{O}_5)_n\cdot\text{OH}$

The general formulae for some important polysaccharides are shown in the table (the numbers of hexose rings are approximate and vary quite a lot).

Name	Molecular formula	General or condensed formula
Dextrin	$23 \text{C}_6\text{H}_{12}\text{O}_6$	$\text{H}(\text{C}_6\text{H}_{10}\text{O}_5)_{23}\cdot\text{OH}$
Starch	$330 \text{C}_6\text{H}_{12}\text{O}_6$	$\text{H}(\text{C}_6\text{H}_{10}\text{O}_5)_{330}\cdot\text{OH}$
Cellulose	$600 \text{C}_6\text{H}_{12}\text{O}_6$	$\text{H}(\text{C}_6\text{H}_{10}\text{O}_5)_{600}\cdot\text{OH}$
Glycogen	$1000 + \text{C}_6\text{H}_{12}\text{O}_6$	$\text{H}(\text{C}_6\text{H}_{10}\text{O}_5)_{1000}\cdot\text{OH}$

Table 1.1: Molecular formulae of some important polysaccharides

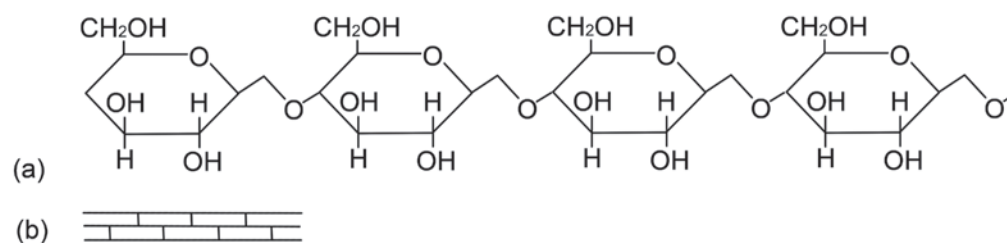
Polysaccharides are the more complex carbohydrates and consist of long chains of simple sugars, as shown in Figures 1.89 and 1.90. They may contain hundreds to thousands of monosaccharide sub-units. The best known polysaccharides are starch, cellulose and glycogen.



a) Part of a starch molecule

b) The general structure of a starch molecule

Figure 1.89: Starch molecule



a) Part of a cellulose molecule

b) The general structure of a cellulose molecule

Figure 1.90: Cellulose molecule

The main functions of carbohydrates in living organisms

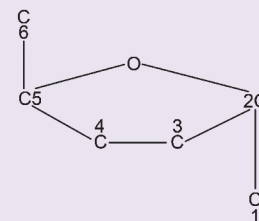
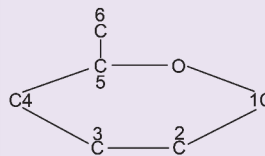
Carbohydrates are important for many different functions:

- Carbohydrates are the most abundant dietary source of energy for organisms.
- They supply energy and also serve as a storage form of energy.
- Carbohydrates such as glucose, fructose, starch and glycogen provide energy for the functioning of living organisms.
- Polysaccharides such as cellulose form structural material for cell walls in plants.
- Carbohydrates participate in cellular functions such as cell growth, adhesion and fertilisation.
- Carbohydrates are utilised as raw materials for several functions such cell growth, adhesion and fertilisation.

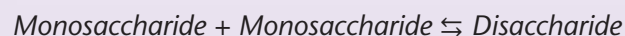
Classroom activity 7

- 1 Say whether the following compounds are monosaccharides or disaccharides:
 - a) maltose
 - b) glucose
 - c) fructose
 - d) lactose
 - e) sucrose
- 2 Name the two monosaccharides that make up each of the disaccharides that you identified in Question 1.

- 3 Analyse the two diagrams below and explain why one is called an aldoring and one is called a ketoring.



- 4 How do galactose and fructose differ from one another?



- 5 Give the general formula for starch. What does the number in the front of the formula refer to?
- 6 Use the following equation, monosaccharide + monosaccharide = disaccharide, to answer the questions that follow:

Homework activity 7

- 1 Name the three elements common to all carbohydrates.
- 2 Give some examples of the role of carbohydrates in nature.
- 3 Explain what a polysaccharide is.
- 4 Name and discuss all of the polysaccharides that you have learnt about in this topic.

Extra practice 7

- 1 Which compounds in nature form the basis of all sweet food?
- 2 Give another name for blood sugar or grape sugar.
- 3 In what form are carbohydrates absorbed from the alimentary canal of animals by the blood stream?
- 4 Where are the following polysaccharides found?
a) lignin b) starch c) glycogen
- 5 Why is a strong fibre feed of plant origin so important for ruminants?

Summary

In this unit we have learnt:

- The basic chemical composition of carbohydrates
- The main classifications of carbohydrates: monosaccharides, disaccharides and polysaccharides (with relevant examples) and their structural formulae
- The general formulae of carbohydrates
- Structural and chemical formulae of carbohydrates
- The main functions of carbohydrates in living organisms.

Topic 2

Soil Science

What will you learn about in this topic?

- The physical and morphological characteristics of soil
 - Soil texture
 - Soil moisture
 - Soil temperature
 - Soil classification and evaluation
 - Soil structure
 - Soil pores
 - Soil profile
- The chemical and colloidal properties of the soil
- Soil organic matter (living and non-living).



Let's talk about this topic

This topic is about the science of soils. The planet Earth has a very thin layer of soil on the surface area of a very small portion of it. The majority of surface area is covered by water (sea). Great parts of the dry land are covered by ice – e.g. the North Pole. Other parts are mountainous and covered by unweathered rock. Only a small portion of the earth's surface area is covered by arable soil. This portion is utilised by mankind to grow food for the increasing populations of the earth.

There is responsibility on our farmers to utilise this soil in such a way that its production potential is not ruined.

Why is soil important?

- Soil is the source of all plant growth (agricultural and non-agricultural)
- Soil contains much of the nutrients and beneficial organisms on the earth
- Soil is the base for all human activity and construction
- Soil is a vital source and filter of our water supply.

What is soil? Soil consists of a variable amount of:

- organic material
- mineral components
- water
- air and pore spaces.

Unit 1: Soil texture

What will you learn about in this unit?

- The concept: soil texture
- The main groupings of soil particles (clay, silt and sand) that determine the soil textures and their respective diameters
- Scientific method to determine the quantity of sand, silt and clay in a soil sample (use of a sieve/mechanical/chemical method)
- Determination of the textural classes (soil texture triangle) of soil and interpretation of textural triangle
- The influences of sand and clay particle size/texture on soil characteristics/behaviour
- The two field methods to determine the soil texture class:
 - Sausage method/feeling method; and
 - Soil texture triangle (use and interpretations).
- The most important reasons for a farmer to know the textural class of his/her farm land.

Let's talk about this unit

This unit deals with the most important physical property of soil – soil texture. The texture of the soil describes whether it is a sandy soil (coarse texture), or a clay soil (fine texture), or somewhere between sandy and clay.

What do I know already?



In Agricultural Science, Grade 10, you have learnt about the primary minerals in soil – the quartz, dolomite calcite, etc. You have learnt that the characteristics exhibited by soil are associated with the type of mineral from which the soil has originated.



Name the characteristics of the quartz mineral and say what role does quartz plays in soil's properties.

Word bank



Capillarity: The degree to which a material or object containing minute openings or passages, when immersed in a liquid (water), will draw the surface of the liquid above the level of zero hydrostatic pressure

Cohesion: The attraction of a substance for itself; the mutual attraction among molecules or particles comprising a substance that allows it to cling together as a continuous mass

Irregular: Not at regular (the same) intervals

Mechanical analysis: Analysis of a substance using mechanical (physical) methods

Micro-pore space: Spaces in soil caused by tiny openings among soil particles.

Plasticity: The property of a soil which allows it to be deformed rapidly without cracking or crumbling and then maintain that deformed shape after the deforming force has been released

Porcelain mortar: Container used in a laboratory made of porcelain

Representative: A sample/person which/who represent the land/population

Scientifically reliable: Reliable because of scientific obtained evidences

Sedimentation: The process of subsidence and deposition or settling of suspended matter carried by water or other liquids, by gravity

Soil texture: The relative proportions of the various separates in the soil as described by the classes of soil texture

Stable ring: A ring formation that does not break

Strip cultivation: Cultivation of land allowing uncultivated strips to prevent erosion

Tillage: The mechanical manipulation of soil for any purpose; but in agriculture it is usually restricted to the modification of soil conditions for crop production

Water retention: Ability of a substance (soil) to hold water

What I still need to know



The size of soil particles determines the texture of that soil. The size of these particles is not subject to ready change – a sandy soil remains sandy and clay remains clay.

Soil texture

The mineral fraction of a soil consists of particles of different sizes and shapes. When soil consists mainly of larger particles it has a coarse texture. When the soil consists of more than 55% of smaller, clay particles, it has a fine texture. Texture is one of the most permanent and important characteristics of soil. Most of the physical properties and many of the chemical properties of a soil are determined by its texture.

Soil texture is concerned with the size of mineral particles. It refers to the relative proportions of particles of various sizes in a given soil.

To study successfully the mineral particles of a soil, they are separated into convenient groups according to size. The analytic procedure by which the particles are separated is called particle-size analysis.

Stone and gravel do not belong to the analysis of the finer soil particles. Their amount is rated separately. The organic matter – usually small in quantity – is removed by oxidation before the mechanical separation of the particle sizes begin.

Sand, when dominant, yields a coarse textured soil, known as sandy soil. Such soils are referred to as light since they are easily cultivated. On the other extreme, soil is made up largely of silt and clay. Its stickiness indicates that it is likely to be difficult to cultivate. It is therefore termed heavy soils. The terms light and heavy refer to the ease of cultivation (tillage) and not to soil weight.

A particle size analysis gives a general picture of the physical properties of a soil. It is also a basis for assigning the textural class name. That is, whether a soil is a sand, sandy loam, loam, etc.

The main groupings of soil particles

The main groupings of soil particles are clay, silt and sand. This determines the soil textures. Soil is classified according to the size of its particles. This is known as the soil fraction.

Table 2.1: The different soil fractions are distinguished as follows:

Fraction	Diameter (mm)	Total Surface Area (cm ² /g)
Very coarse sand	10,0 – 2,0	11
Coarse sand	2,00 – 0,50	23
Medium sand	0,50 – 0,20	45
Very fine sand	0,20 – 0,02	91
Silt	–	227
Clay	0,02 – 0,002	454
	Smaller than 0,002	8 000 000

The physical nature of the different soil fractions (groupings) can be summarised as follows:

Sand

Sand particles may be rounded or quite irregular – depending on the amount of weathering they have received. Sand particles are not sticky, even when wet. They do not possess the capacity of plasticity as does clay. Their water holding capacity is low. Because of the large size of the spaces between the separate particles, the passage of water and air is rapid. Because of this drainage and air movement is good.

Clay and silt

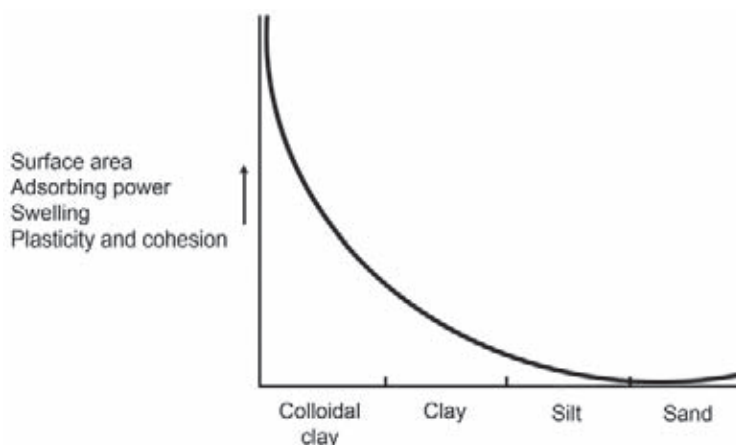


Figure 2.1: Surface area and adsorption power

The surface area of clay and silt is most affected by the small size and fine sub-division of this group. Fine colloidal clay has about 10,000 times as much surface area as the same weight of medium sized sand. The adsorption of water, nutrients and the attraction of particles for each other are all positively influenced by this huge surface area of clay particles.

The finer the texture of a soil, the greater is the effective surface exposed by its particles. Adsorption, swelling, plasticity and cohesion follow the same general trend as their intensity goes up rapidly as the colloidal size (of clay) is approached.